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POINTE COUPEE PUMPING STATION SIPHON, UPPER POINTE COUPEE LOOP --ETC(U)
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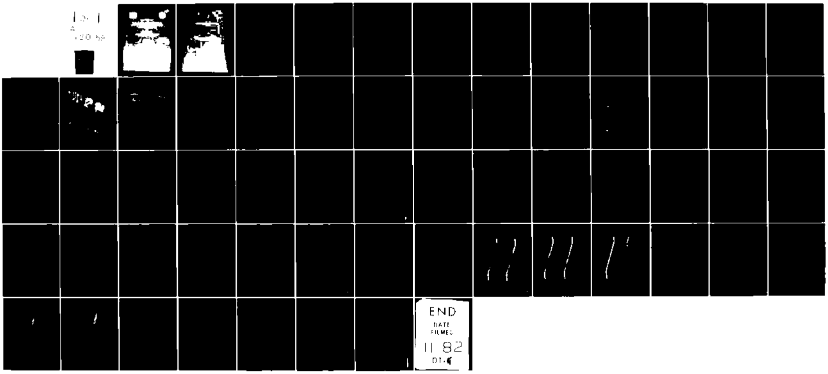

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Hydraulic models were used to evaluate the hydraulic performance of the Pointe Coupee pumping station siphon. A trap design was developed to ensure maintenance of the priming seal and to prevent excessive negative pressures at the siphon crown. The diameter of the siphon was reduced to obtain adequate priming velocities. Use of deflectors to induce priming was also (Continued)		

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20. ABSTRACT (Continued).

tested. Pressure fluctuations and head losses were measured in the model. Scale effects inherent to siphon modeling are discussed. The recommended design siphon operated satisfactorily for the entire range of expected tailwaters and discharges.

PREFACE

The model investigation of the Pointe Coupee pumping station siphon, reported herein, was authorized by the Office, Chief of Engineers (OCE), U. S. Army, on 14 February 1978, at the request of the U. S. Army Engineer District, New Orleans (LMN).

This investigation was conducted during the period September 1979 to April 1981 in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES), under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Mr. J. L. Grace, Jr., Chief of the Hydraulic Structures Division, and under the general supervision of Mr. N. R. Oswalt, Chief of the Spillways and Channels Branch. Project Engineer for the model study was Mr. R. R. Copeland, assisted by Mr. E. L. Jefferson. Mr. E. B. Williams is acknowledged for his work in constructing the model. This report was prepared by Mr. Copeland.

During the course of the study, Messrs. Cecil W. Soileau, Mike Sanchez-Barbudo, Reynold Broussard, and David Hays of LMN; Hugh E. Wardlaw, John B. Harman, and Guy Forney of the Memphis District; Joe McCormick, Larry Cook, Larry Eckenrod, and Roddis C. Randell of the Lower Mississippi Valley Division; and John S. Robertson of OCE visited WES to discuss the program of model tests, observe the model in operation, and correlate test results with concurrent design work.

Commanders and Directors of WES during conduct of this investigation and the preparation and publication of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831865	cubic metres per second
Fahrenheit degrees	*	Celsius degrees or Kelvins
feet	0.3048	metres
feet of water	0.03048	kilograms per square centimetre
feet per second	0.3048	metres per second
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres
square miles	259.0	hectares

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

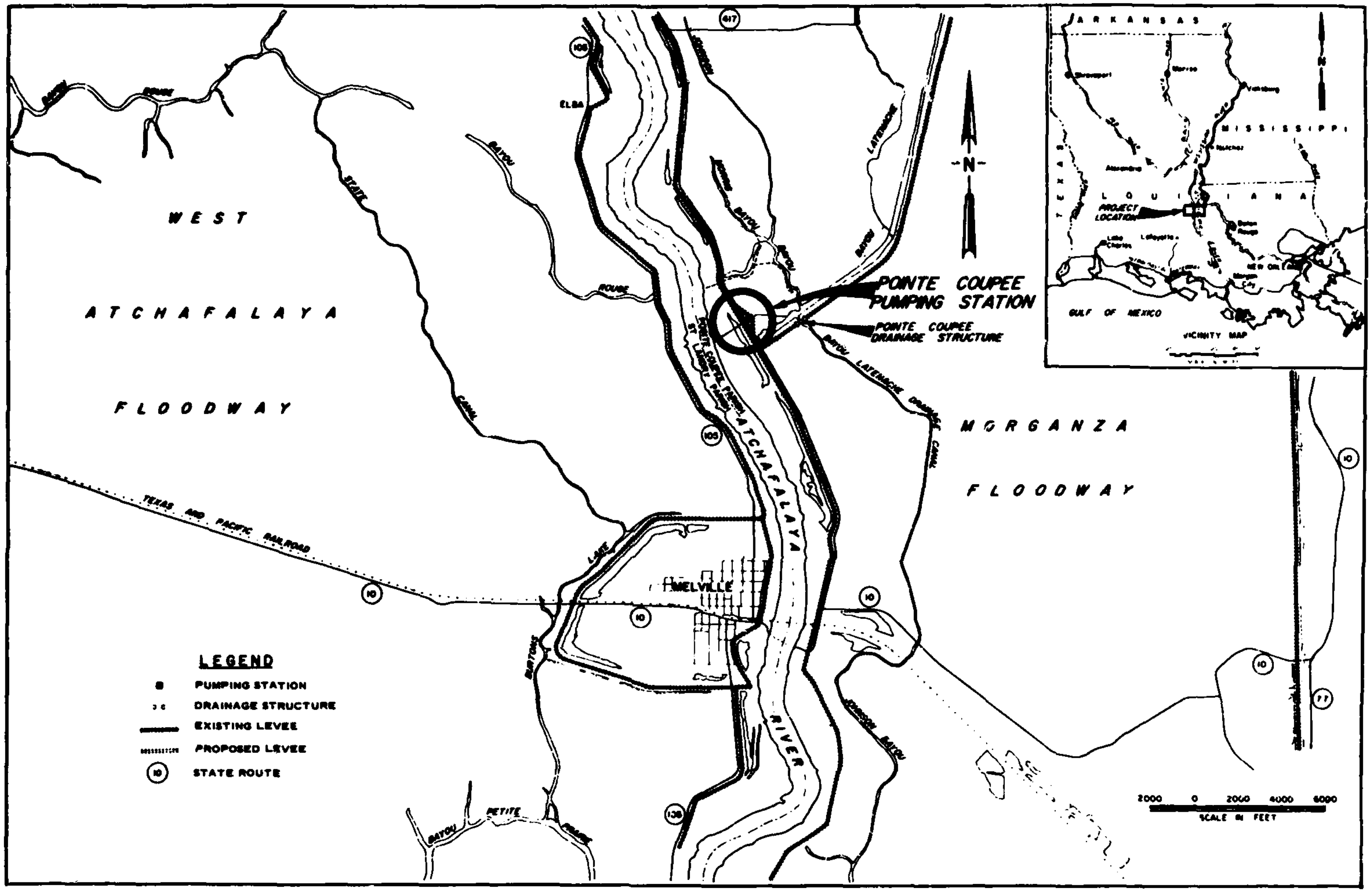

Figure 1. Location map

POINTE COUPEE PUMPING STATION SIPHON

UPPER POINTE COUPEE LOOP AREA, LOUISIANA

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. Site of the proposed Pointe Coupee pumping station, to be located in south-central Louisiana in the northernmost portion of Pointe Coupee Parish (Figure 1), is 2 miles* north of the town of Melville and about 32 miles northwest of Baton Rouge. The 128-square-mile drainage area is called the Upper Pointe Coupee loop and comprises primarily cropland, pastureland, and forestland. The area is enclosed by the Mississippi, Old, and Atchafalaya River levees and by the Morganza Floodway upper guide levee. Bayou Latenache and Johnson Bayou, the principal streams draining the area, collect rainfall runoff and convey the water to the existing Pointe Coupee gravity-flow drainage structure where it is discharged into the Morganza Floodway. The proposed Pointe Coupee pumping station would be located about 0.5 mile west of the gravity-flow drainage structure and would discharge flows into the Atchafalaya River.

2. Drainage of the Upper Pointe Coupee loop area was blocked by the construction of the upper guide levee of the Morganza Floodway which carries excess Mississippi River floodwaters to the Atchafalaya Basin Floodway. To provide for this drainage, the gravity-flow drainage structure was constructed. Extra storage was provided in the borrow pits that had been used to build the levee, and flood easements were purchased over some 20 square miles in the loop area located below

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

el 35.0, NGVD.* However, flooding continued to affect the area due to an inadequate system of interior drainage and insufficient capacity of the drainage structure. High flood stages occurred in 1973 when the Morganza Floodway was operated for the first time. The high stage in the floodway necessitated the closing of the Pointe Coupee drainage structure. This action effectively prevented the floodwaters in the Morganza Floodway from entering the Pointe Coupee loop area; however, it also prevented any accumulated runoff within the area from draining. Eight inches of rain fell on the loop area while the floodway was operating. Serious flooding was prevented by placing into action 41 portable pumps with a total rated capacity of 1,400 cfs. This emergency measure was successful in keeping water levels in the area from exceeding el 34.0, 1 ft below the flood easement elevation. The proposed Pointe Coupee pumping station would provide for improved drainage and flood control in the loop area, even during operation of the Morganza Floodway.

3. The proposed pumping station will have three vertical 72-in. pumps operating with siphonic recovery. Design discharge for the station is 1,500 cfs, although the discharge per pump will range between 350 and 680 cfs depending on the operating head and manufacturer that will be awarded the contract for the pumps. The expected priming discharge will range between 350 and 460 cfs depending on the water level in the sump at the time of pump start-up and the actual pump manufacturer. The pumps will be started with a sump water-surface elevation of 21.0 ft and stopped when it is lowered to el 20.0. The maximum design sump water-surface elevation will be 26.0 ft.

4. Three steel discharge pipes will carry flow over the Atchafalaya River levee into the outlet structure. An air vent located at the crown or summit of the siphon will be opened at the time of pump start-up to relieve positive pressures that accompany the initial phase of siphon operation. The air vent will then be closed to initiate the priming phase. When the pumping operation is completed, the air

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* All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGCD).

vent will be opened to break the siphon and prevent backflow. Another air vent located in the top of the pipe at el 31.0 will always be open and will serve to limit the negative pressure at the siphon crown to a maximum of 28 ft of water. Negative pressures in excess of 28 ft of water would probably cause cavitation. At the end of the discharge pipe, an increaser will be used to transition from the circular cross section to a 10- by 10-ft box section at the outlet portal upstream of the stilling basin. The tailwater will range between el 3.1 and 46.0. A profile of the type 1 (original) design siphon is shown in Figure 2.

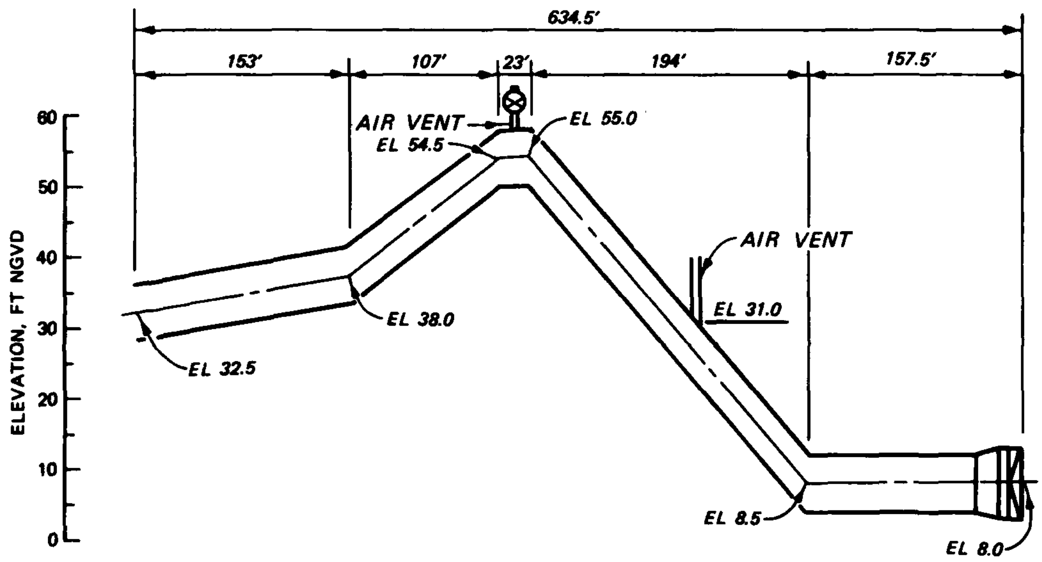

Figure 2. Profile of type 1 (original) design siphon

Purpose of the Model Study

5. Design criteria for pumping station siphons are generally lacking. Pumping station siphons differ from siphon spillways (which are capable of rapid increases in discharge and for which there is considerable design guidance) in that discharge is limited by the relatively constant capacity of the pump. This makes it essential that

the siphon prime with the minimum discharge capacity of the pump and prevent "washout" with the maximum priming discharge of the pump. Also, friction losses are typically more important in pumping station siphons and form losses are more important in siphon spillways. A model study was therefore recommended and conducted to develop a satisfactory siphon design that will ensure maintenance of a priming seal, adequate priming characteristics, and desired hydraulic performance.

6. It became apparent during the operation of the 1:19.2-scale stilling basin model (which included the 8-ft-diam discharge pipes from the siphon crown into the stilling basin) that the type 1 (original) design siphon would not prime with the lower tailwater expected. This was due to the open air vent at el 31.0 and the unsubmerged outlet. Without siphonic head recovery, the proposed pumps would not be able to deliver the design discharge.

PART II: THE MODELS

Description

7. The Pointe Coupee pumping station siphon was studied using three models at undistorted linear scales of 1:19.2, 1:16.8, and 1:9.6. Initially, the siphon was studied in conjunction with the stilling basin model constructed to a scale of 1:19.2 and only the downstream leg of the type 1 (original) design siphon was simulated (Figure 3). The siphon was constructed of transparent plastic pipe so that hydraulic flow conditions could be easily observed. Air vents at the siphon crown and at el 31.0 were simulated. The increaser at the siphon outlet and entrance to the stilling basin was also simulated. The type 2 design siphon was also studied with the 1:19.2-scale model used for design of the stilling basin. The entire length of the siphon was simulated and the landward (upstream) leg of the siphon model was constructed of PVC pipe. The air vents, increaser, and stilling basin were all simulated in this model. After a number of tests, it was determined that the 1:19.2-scale model would not accurately simulate transport of air bubbles and hydraulic conditions during the priming. The type 3 and 4 design siphons were tested with a 1:9.6-scale model, constructed of transparent plastic, which simulated the entire siphon length (Figure 4). These designs called for reducing the siphon diameter from 8 to 7 ft. The increaser and stilling basin were not simulated because their effect on priming is negligible. In order to evaluate model scale effects, a 1:16.8-scale model of the type 4 (recommended) design siphon was constructed (Figure 5). Space did not allow for simulation of the first 180 ft downstream from the pump, but priming operations are not affected by this portion of the siphon. The increaser and stilling basin at the downstream end of the 1:16.8-scale model were not to scale, but this does not affect the priming characteristics significantly.

8. Flow through the models was recirculated by centrifugal pumps. In the 1:19.2-scale model of the type 1 (original) design siphon, flow

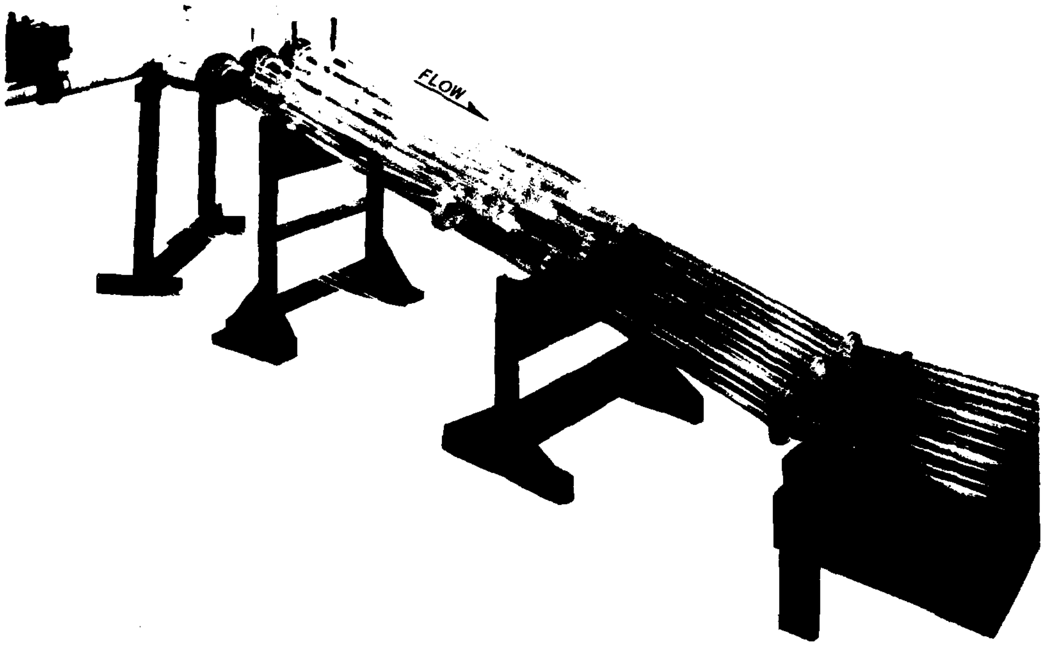

Figure 3. Type 1 (original) design siphon, 1:19.2-scale model

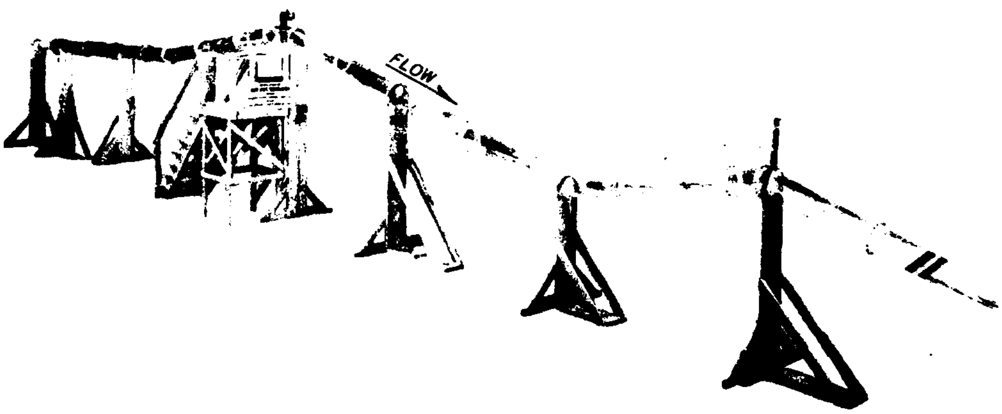

Figure 4. Type 3 design siphon, 1:9.6-scale model

Figure 5. Type 4 (recommended) design siphon, 1:16.8-scale model

was measured by paddle-wheel flowmeters and displayed electronically. In the 1:19.2-scale model of the type 2 design siphon and the 1:16.8-scale model of the type 4 design siphon, flow was measured using an elbow meter and manometer that was calibrated volumetrically in an adjacent tank. In the 1:9.6-scale model, flow was measured by an elbow meter and manometer that was calibrated using a V-notched weir. Flow rates were controlled with manually operated valves.

9. Hydrostatic pressures in the models were measured with piezometers and with an electronic pressure cell mounted flush with the bottom of the pipe. Pressures were measured with piezometers at 28 locations on the 1:9.6- and 1:16.8-scale models and at six locations on the 1:19.2-scale model. These locations are shown in Plate 1. The two piezometer taps at each station were connected, so that the reading represented an average. The electronic pressure cell was located 35 ft (prototype) downstream from the pump in the 1:9.6-scale model, far enough downstream from the start of the 7-ft-diam pipe to avoid any flow disturbances that might have been introduced by the transition at the upstream end of the model. The pressure cell was used to measure instantaneous pressure fluctuations due to hydraulic forces that would be expected to occur at the prototype pump. Accelerometers and an oscilloscope were used with the model to determine the frequency of

pressure fluctuations due to vibration of the model pumps and the model itself. These pressure fluctuations, which are strictly related to the model and do not simulate prototype vibrations, were found to have a higher frequency than the pressure fluctuations due to hydraulic forces. The high-frequency pressure fluctuations were filtered electronically, and only the pressure fluctuations due to hydraulic forces were recorded. The piezometers were used to measure the average hydrostatic pressure, and the electronic pressure cell was used to measure instantaneous pressure fluctuations.

10. Air flowed into the siphon through two air vents, one at the siphon crown and one at el 31.0. Air vent diameters were geometrically similar to those in the prototype. Airflow was measured by a hot-wire anemometer in the 1:9.6- and 1:16.8-scale models. The air vent was extended sufficiently to ensure uniform velocity distribution at the point of air velocity measurement. Airflow measurements were used to evaluate model scale effects on air demand and transport between the 1:9.6- and 1:16.8-scale models.

Interpretation of Model Results

11. The principle of dynamic similarity, which requires that the ratios of forces be the same in the model and prototype, is the basis for the design of the models and the interpretation of results. The hydraulic performance of a siphon is affected by inertial forces (forces resulting from changes in the magnitude or direction of the velocity), gravitational forces, viscous forces, and surface tension. It is not practical, in this case, to conduct a model investigation in which all of the forces influencing flow are scaled correctly. However, during certain operating conditions when fundamental flow characteristics are the same in the model and prototype systems, the differences in force ratios are negligible or can be accounted for by calculating adjustments to the model results. For other operating conditions, these forces are not negligible and only qualitative model results are possible. These qualitative model investigations are useful in evaluating the relative

merits of one design compared with another. The hydraulic conditions of primary interest in this model study are influenced predominantly by gravitational and inertial forces; therefore, the model was constructed and operated based on the Froudian criteria.

12. When the siphon is flowing full (after being primed), the forces influencing hydraulic performance are gravity, viscosity, and inertia. It is the gravitational and inertial forces that predominate at the outlet where flow is discharged into the outlet channel and the viscous and inertial forces that predominate in the pipe itself. It has been established by several investigators involved in siphon model studies (Gibson, Aspey, Tattersall 1931; Whittington and Ali 1972) and is generally accepted (Naylor 1935; CBIP 1956; Babb, Amorocho, Dean 1967; Head 1975) that if the Reynolds number of flow in the model exceeds 1.8×10^5, then in cases where friction is negligible, the viscous scale effects will be negligible. When friction losses are not negligible, adjustments to the model or to the model results can be made to account for scale effects due to friction. Thus, if the model is constructed large enough so that the Reynolds number of flow exceeds 1.8×10^5, then viscous effects are insignificant and the Froudian criteria can be applied.

13. The siphon investigation was conducted at three different scales. Initially, the siphon was operated as a part of the stilling basin model at a 1:19.2 scale. At this scale, the Reynolds numbers ranged between 0.7×10^5 and 1.3×10^5. Recognizing the viscous scale effects at this scale, a larger model was constructed at a 1:9.6 scale. Reynolds numbers ranged between 2.0×10^5 and 4.2×10^5 in the larger model. At the conclusion of the study, the final recommended design was also constructed to a 1:16.8 scale in order to study model scale effects. (The same pipe used in the 1:19.2-scale model was used in this model but the scale was reduced because during the course of the investigation the diameter of the siphon was reduced from 8 to 7 ft.) In this model, the Reynolds number ranged between 0.9×10^5 and 1.8×10^5. The 1:9.6-scale model was deemed large enough to study full flow conditions because viscous effects could be considered

negligible if adjustments were made to the model results to account for friction scale effects.

14. When the siphon is flowing partially full (with the air vent at the crown open or during priming), the hydraulic performance is influenced by the forces of gravity, viscosity, inertia, and surface tension. The process of air entrainment by the hydraulic jump has been shown to be primarily a function of the Froude number and pipe slope (Kalinske and Robertson 1943, Kent 1953, Renner 1975, Wilhelms et al. 1981). When the pipe downstream from the hydraulic jump is horizontal or is sloping upward, most of the air entrained by the jump is removed from the pipe (Falvey 1980). However, when the pipe slopes downward, the process of air transport downstream from the jump becomes important. This process is highly influenced by surface tension and viscosity. The entrained air bubbles will have approximately the same still water rise velocities in the model and prototype (Ervine and Elsawy 1975); giving a nonscaling of air transport. Several investigators have observed significant scale effects in air transport in siphon models (Naylor 1935; CBIP 1956; Babb, Amorocho, Dean 1967; Ervine and Elsawy 1975, Thatcher and Brattson 1975).

15. Due to the scale effect in modeling air transport in siphons, priming times will be longer in the model and the ability to maintain the priming seal at pump start-up may be overestimated. With respect to priming time, if adequate priming action exists in the model, it is safe to conclude that the prototype priming action will be at least as good and probably better. With respect to maintaining the priming seal, the model scale effect will have an opposite impact. If more air is entrained in the prototype, the weight of the water and air column, which holds the hydraulic jump in the siphon, will be reduced. If this weight is reduced significantly the priming seal will wash out of the siphon. The model scale effects related to washout are not as critical in this case as might be imagined because the pipe slopes upward downstream from the hydraulic jump, and air entrainment is primarily a function of the Froude number of flow. It remains prudent to provide a safety factor in designing for washout when the design is based on model results. Scale

effects associated with siphon modeling are reduced as the size of the model is increased. It is essential that a siphon model be large enough to minimize scale effects on the most fundamental character of flow--the transport of air. To date, research has not established an appropriate scale to adequately model siphon priming or washout, and model results must be interpreted with care.

16. General relations expressed in terms of the model scale or length ratio are as follows:

Dimension	Ratio	Scale Relation		
Length	$L_r = L$	1:9.6	1:16.8	1:19.2
Velocity	$V_r = L^{1/2}$	1:3.098	1:4.099	1:4.382
Time	$T_r = L^{1/2}$	1:3.098	1:4.099	1:4.382
Discharge	$Q_r = L^{5/2}$	1:285.5	1:1157	1:1615
Pressure	$P_r = L$	1:9.6	1:16.8	1:19.2
Frequency	$f_r = L^{-1/2}$	1:0.3227	1:0.2440	1:0.2282

Values for discharge, velocity, hydraulic grade line, and pressure fluctuation can be transferred quantitatively from the model to the prototype by means of the scale relations above. Values for priming time can only be transferred qualitatively. Unless otherwise noted, all results reported herein will be in prototype units.

PART III: TEST RESULTS

Method of Operation

17. The discharges simulated in the model ranged between 350 and 680 cfs; tailwaters ranged between el 3.1 and 46.0. Head loss measurements were made after steady flow was established. In cases where the hydrostatic pressures fluctuated, the lowest reading of the piezometer was recorded. To study priming characteristics, the discharge was set with the air vent at the siphon crown open. Priming was initiated by closing the air vent; and the priming operation was timed with a stopwatch. The siphon was considered to be primed when all the air was removed from the downward leg of the siphon upstream from the trap. Discharge was checked at the end of the test, and no significant changes were noted. Two priming operations were simulated with the discharge increased as the head decreased. Head-discharge relationships for these simulations were taken from the possible pump characteristic curve shown in Plate 2. In these simulations, discharge was increased by manually opening the regulating valve on the model so that the simulated discharge corresponded approximately to the head measured by the piezometer board and expected for the pump characteristic curve. These simulations were not intended to reproduce actual prototype priming times, but to develop a comparison between priming times with constant and varying discharges. To study the capability of the siphon to maintain a priming seal, the upward leg of the trap was filled with water by allowing a very small flow in the siphon. It is very important that the trap be filled with water before any significant flow is allowed through the siphon. If the trap is empty, the supercritical flow coming down from the crown will have sufficient momentum to flow up the adverse slope and over the trap crown without forming a hydraulic jump and priming seal. Once the trap was full of water, the discharge could be increased to simulate possible prototype priming discharges. Washout tests were run with the air vent at the siphon crown open. Discharge was increased in steps until the priming seal was washed out of the trap.

Original Design Siphon

18. The original design siphon consisted of a 641-ft-long, 8-ft-diam pipe that extended from the pumping station, over and down the levee slope, to the stilling basin and the Atchafalaya River. An air vent was located on the downward leg of the siphon and was designed to limit the negative pressure in the siphon crown to 28 ft of water. The type 1 (original) design siphon is shown in Figure 2.

19. Expected priming discharges for the siphon ranged between 350 and 460 cfs depending on the sump water-surface elevation and the expected pump performance characteristics. When this range of discharges was tested in the model at tailwater elevations that did not submerge both the outlet and the air vent at el 31.0, a priming seal could not form in the siphon and priming could not commence. Modifications to the original design siphon were necessary in order to ensure that a priming seal would be maintained throughout the range of design tailwaters.

Nappe Deflectors

20. The feasibility of using nappe deflectors to force priming of the siphon was investigated in the 1:19.2-scale model of the type 1 (original) design siphon. Nappe deflectors were placed in the bottom of the siphon upstream from the air vent and at the siphon crown. In order for the deflectors upstream from the air vent to function properly, the flow trajectory must intercept the top of the pipe upstream from the air vent with sufficient coverage to separate the upstream and downstream air pockets. This allows a pressure differential to develop between the air pockets and ultimate priming to occur as air is entrained and removed from the upstream air pocket. Deflectors located at the siphon crown induce priming by forcing the siphon to flow full at the top in hopes that drag forces will be sufficient to continue the priming process by forcing full pipe flow in a downstream direction. Nappe deflectors ranging in size from 10 to 40 percent of the pipe's cross-sectional

area were tested in the model and are shown in Figure 6.

21. The type 1 design deflector consisted of a 45-deg sloping deflector located on the bottom of the pipe at el 29.0. The deflector produced a cross-sectional area reduction of 10 percent. At the minimum priming discharge of 350 cfs, flow was deflected upward without reaching the top of the pipe. At a discharge of 400 cfs, the trajectory touched the top of the pipe, but priming did not occur. When the discharge was increased to 600 cfs the deflector did not function--only a slight increase in depth occurred in the supercritical flow profile as flow passed over the deflector. The type 1 design deflector was too small to force priming.

22. The type 2 design deflector was also located at el 29.0, but was larger than the type 1 design, obstructing 25 percent of the pipe's cross-sectional area. With the minimum priming discharge of 350 cfs, a hydraulic jump was formed upstream from the deflector. The hydraulic jump was unstable, characterized by forward and backward surging and the siphon did not prime. Conditions were similar for discharges up to 600 cfs. At a discharge of 600 cfs. the siphon filled at the crown and primed due to friction or hydraulic resistance in the downstream remainder of the siphon. The type 2 design deflector was too small to force priming at expected priming discharges. Further increases to the deflector's size would result in excessive head losses in the siphon after priming. Therefore, tests to evaluate nappe deflectors at this location were discontinued.

23. An attempt was made with the type 3 and 4 design nappe deflectors to force priming by locating the deflectors at the siphon crown (el 51.0). The type 3 design deflector was the same size as the type 1 design, obstructing 10 percent of the pipe's cross-sectional area. At a discharge of 350 cfs, the type 3 design deflector caused the flow trajectory to hit the top of the pipe but did not induce priming. At a discharge of 600 cfs, rapid priming was induced at the crown. The size of the deflector was increased so that 40 percent of the cross-sectional area was obstructed in the type 4 design deflector. No significant difference was observed in the performance of the type 3 and 4

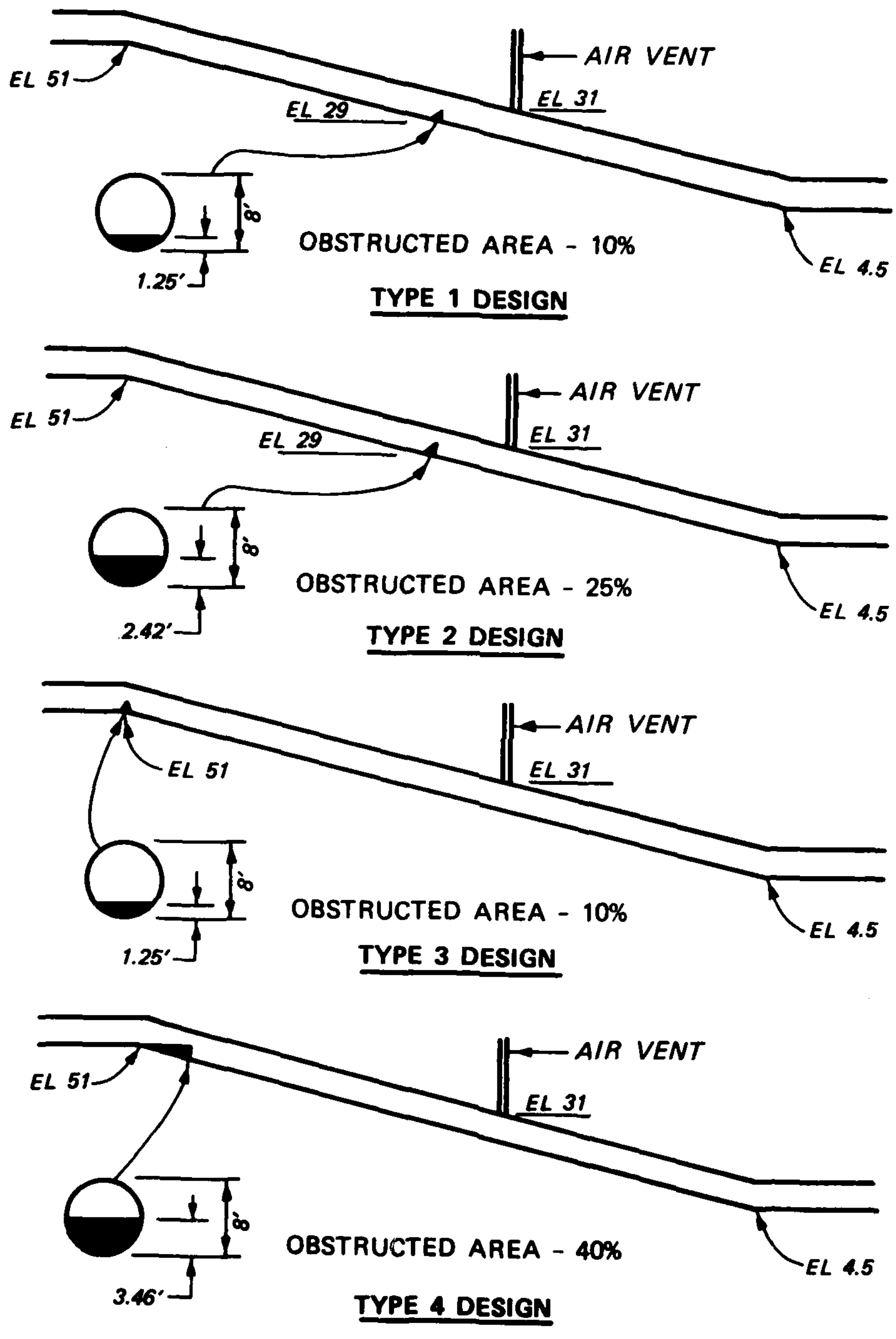

Figure 6. Nappe deflector designs

designs. It was concluded that crown deflectors would not function adequately unless the size of the pipe was significantly reduced or the minimum priming discharge was significantly increased.

Experimental Trap Designs

24. A trap design as shown in Figure 7 was used in the 1:19.2-scale model to ensure the formation of a priming seal. The weight of

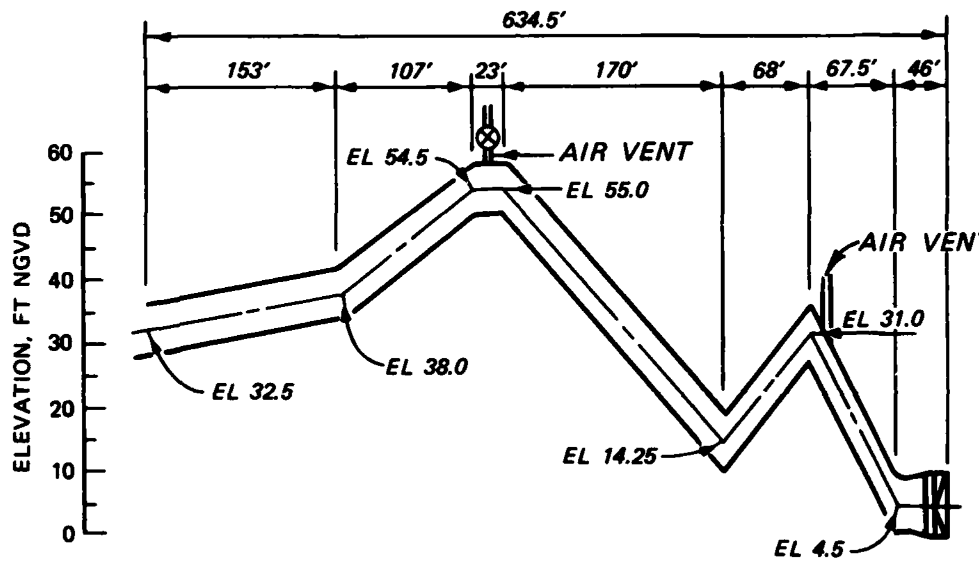

Figure 7. Profile of type 2 design siphon

water in the adverse sloped portion of the trap must be sufficient to hold the hydraulic jump in the siphon at the start of priming with the maximum expected priming discharge. This requirement can be determined using the momentum equation (Figure 8).

$$\gamma a_1 \bar{y}_1 \cos\theta + \frac{\gamma Q V_1}{g} = \frac{\gamma a_2}{1+\beta}(h + h_f) + \frac{\gamma Q^2 (1+\beta)}{g a_2} - W \sin\theta$$

where

γ = specific weight of water

a_1 = cross-sectional area of flow upstream from the hydraulic jump

$\bar{y}_1$ = distance from the water surface to the centroid of the cross-sectional area of flow upstream from the jump

θ = trap angle measured in degrees between horizontal and downward leg of siphon

Q = discharge

V_1 = average velocity upstream from jump

g = acceleration due to gravity

a_2 = cross-sectional area of the pipe

β = air-water flow ratio

h = difference between water-surface elevation at trap crown and the center of the pipe at the bottom of the trap

h_f = friction head loss in the upward leg of the trap

W = weight of water in hydraulic jump

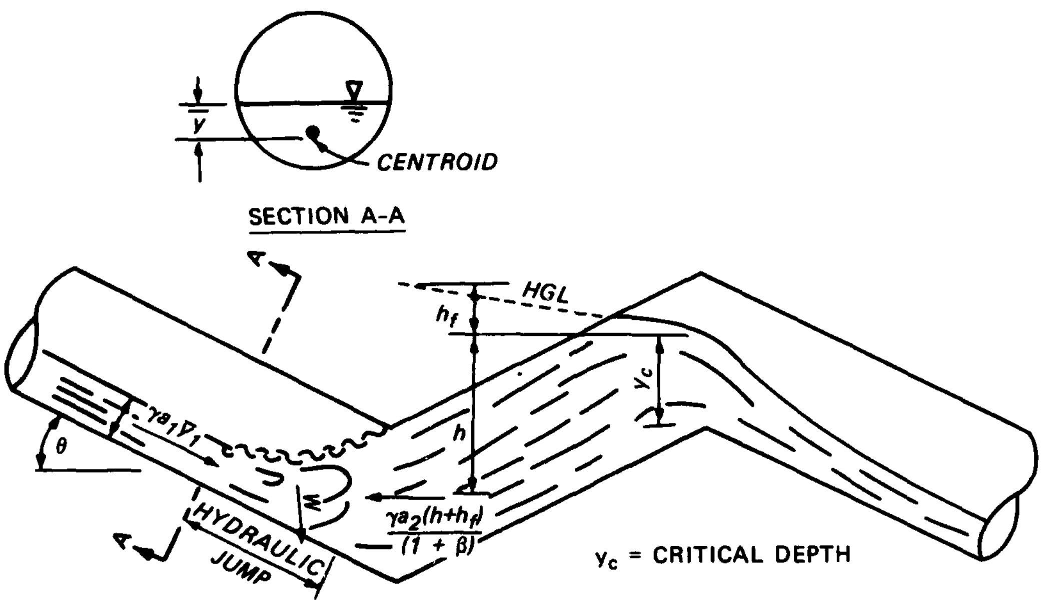

Figure 8. Definition sketch for momentum equation

The upstream hydraulic parameters can be determined by computing a standard step backwater for supercritical flow from the crest down the riverward leg of the siphon. The weight of water in the hydraulic jump is a function of the length of the jump and must be estimated from empirical data. The ratio of entrained air to water discharge is a

function of Froude number and slope and must also be estimated empirically.

25. The type 2 design siphon had a 16.75-ft-high trap with a crest invert at el 27.0. The siphon was designed to contain the hydraulic jump for the maximum priming discharge of 460 cfs and to ensure that the maximum negative pressure at the crest did not exceed 28 ft of water. The type 2 design siphon was tested at a 1:19.2 scale. The trap design was found to be adequate in maintaining the priming seal. However, the type 2 siphon would not prime within the designated range of priming discharges. When the discharge was increased to 600 cfs the siphon primed in 84 min. Tests demonstrated that the model velocities were not high enough to remove air entrained by the hydraulic jump upstream from the priming seal. Due to the relatively small scale (1:19.2) of the model, it cannot be concluded that the prototype would not prime at the simulated discharges. However, it was the intent of the model investigation to develop a design that would prime in the model, thus ensuring that the prototype would also prime.

26. The type 3 design siphon had a 14.95-ft-high trap with a crest invert at el 24.0. The diameter of the siphon was reduced from 8 to 7 ft. An additional 30 ft of length was added to the downstream end of the siphon to account for design changes related to the stilling basin. The increaser at the end of the siphon was not simulated, because it has no significant effect on priming characteristics. The trap height was reduced in the type 3 design siphon because the type 2 design had been able to contain a discharge of 600 cfs which is much higher than the expected pump capacity at the start of priming. The trap crest elevation was lowered because the siphonic recovery determined in the type 2 design siphon tests was less than 28 ft of water. The pipe diameter was decreased so that the velocity would be greater and the air transport capabilities during priming would be improved. The type 3 design siphon is shown in Figure 9.

27. The type 3 design siphon was modeled at a 1:9.6 scale. Priming characteristics were determined for constant discharges ranging from 350 to 425 cfs. Hydraulic characteristics of the siphon during priming

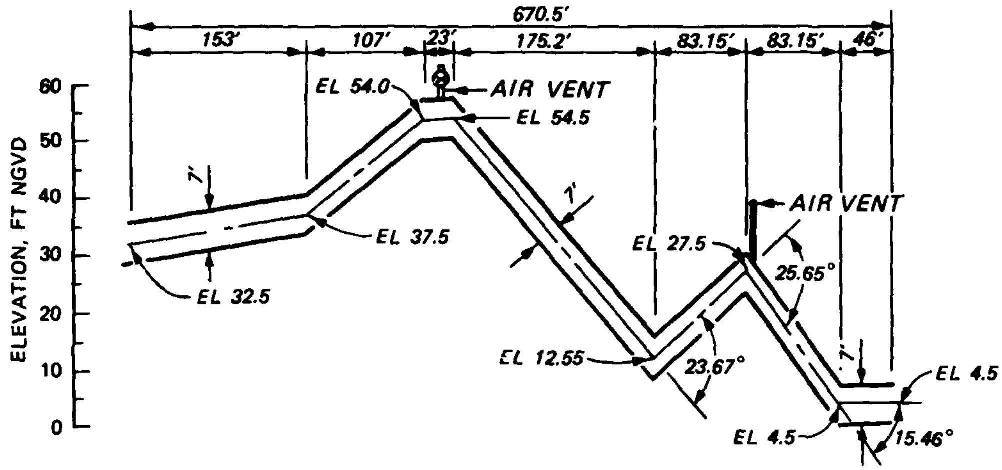

Figure 9. Profile of type 3 design siphon

are shown in a series of photographs (Photos 1-5) for a constant discharge of 425 cfs. In Photo 1 the air vent at the siphon crown is open and the hydraulic jump is stationary just upstream from the trap. Initially, the air vent is opened to relieve the positive pressure that accompanies pump start-up. When the air vent is closed, the priming process begins. The hydraulic jump entrains air that must be transported down the pipe by the flow. Initially, air removal is rapid and the hydraulic jump moves quickly up the siphon (Photo 2). As the distance required for air transport increases, the air removal rate decreases. Large air pockets form downstream from the jump (Photo 3) and move upstream, eventually breaking through the hydraulic jump. When this happens, the hydraulic jump moves slightly downstream, so that the general upward progress of the jump is characterized by pulsations. As the hydraulic jump nears the siphon crown, only a small percentage of the air entrained by the jump is actually transported out of the siphon (Photo 4). Air bubbles entrained by the hydraulic jump eventually rise to the top of the pipe and form small air pockets. These air pockets will continue to move downstream as long as the drag forces provided by the flow are large enough to overcome their buoyant forces. The final stages of priming are characterized by a steady train of small

air pockets moving upstream and air bubbles being gradually transported downstream out of the siphon. The siphon in its primed condition is shown in Photo 5. Due to the hydraulic characteristics of the priming process, the siphonic recovery is rapid during initial phases of priming and much slower during the final stages of priming. The relationship between total energy head at the pump and time for various constant discharges is shown in Figure 10. The model of the type 3 design siphon was capable of priming with the minimum priming discharge of 350 cfs.

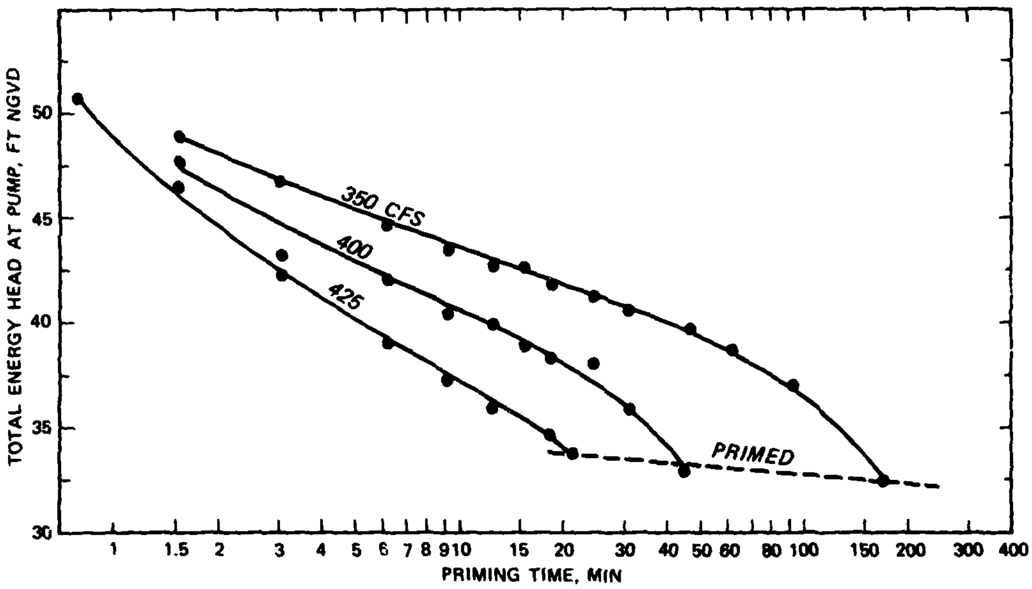

Figure 10. Priming characteristics of type 3 design siphon with constant discharges and tailwater below outlet

Priming times shown are for constant discharges; in the prototype, the discharge will be increasing as the head on the pump decreases due to siphonic recovery. This means that priming under actual prototype conditions will be more rapid. This difference will be significant at low tailwaters, but much less significant at high tailwaters where siphonic recovery is much less.

28. The type 3 design siphon was capable of priming at the minimum expected priming discharge of 350 cfs, but at the maximum expected priming discharge of 460 cfs, the priming seal washed out. This washout

is shown in progress in Photo 6. The washout occurred with the crown air vent open and represents conditions just before the initiation of priming. In order to ensure maintenance of the priming seal, the trap height had to be increased.

Recommended Design

29. In the type 4 (recommended) design siphon, the height of the trap was increased by 2.36 ft to a total of 17.31 ft. This change required that the trap angles also be increased slightly. The crest invert elevation remained at 24.0 and the siphon diameter (7 ft) was not changed. The type 4 design siphon is shown in Figure 11.

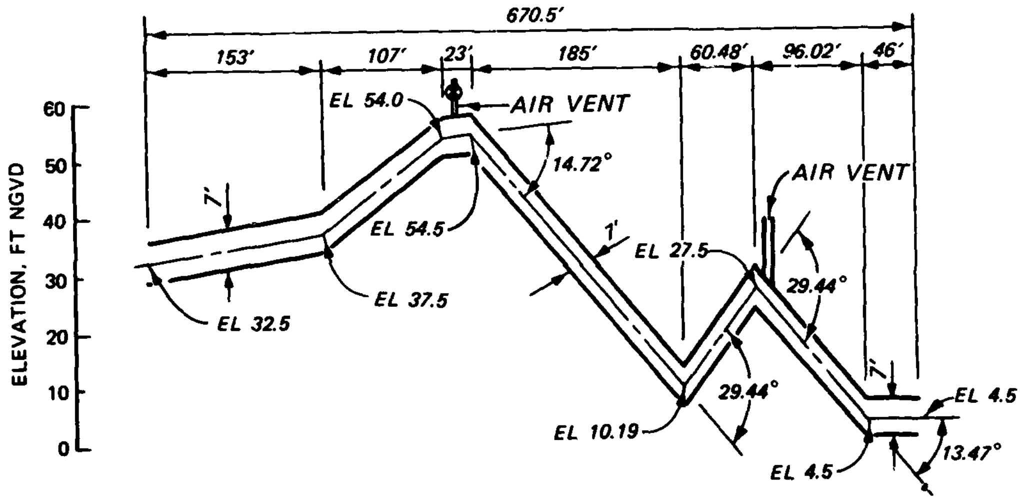

Figure 11. Profile of type 4 (recommended) design siphon

30. Priming times and washout potential were determined in the 1:9.6-scale model of the type 4 design siphon. The model indicated that this siphon was capable of priming with the minimum priming discharge of 350 cfs. Priming times were longer than with the type 3 design siphon because the downstream leg was longer. The relationship between total energy head at the pump and priming time for various constant discharges is shown in Figure 12. Actual priming times will be less in the prototype because discharge will increase with siphonic

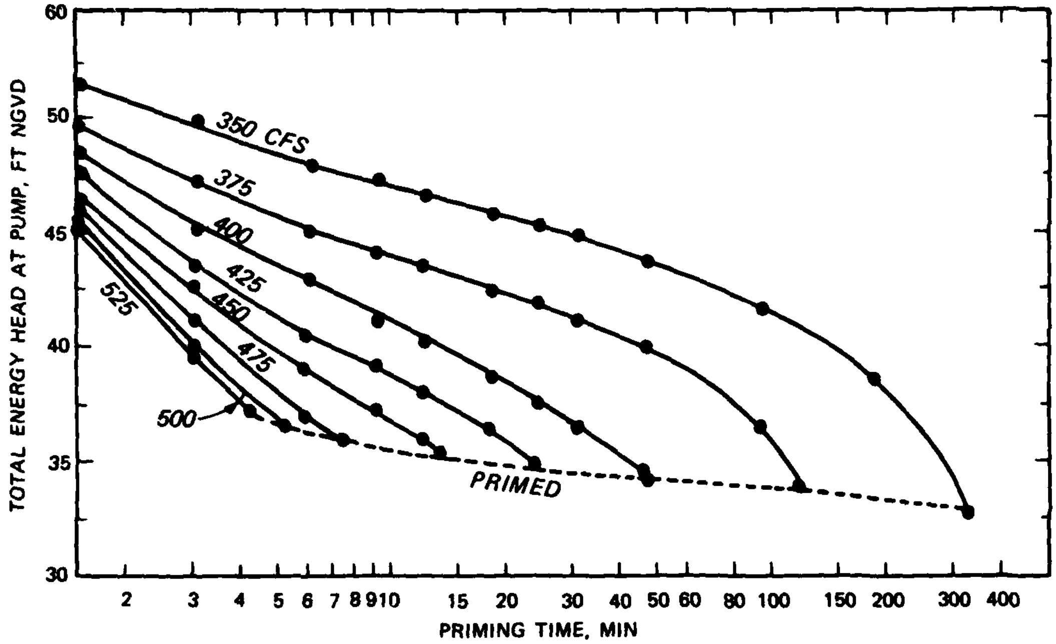

Figure 12. Priming characteristics of type 4 (recommended) design siphon with constant discharges and tailwater below outlet

recovery, rather than remain constant as in the model which did not include means for simulating actual pump characteristics. Washout tests were conducted with the air vent at the crown open, and the model discharge was increased in increments until washout occurred. At the maximum expected priming discharge of 460 cfs, the priming seal was stable. Washout did not occur until the discharge was increased to 530 cfs, providing a safety factor of 70 cfs. Hydraulic performance of the type 4 design siphon was deemed satisfactory and it is the recommended design.

Operating Head Losses

31. The 1:9.6-scale-model siphon was used to estimate the total heads or maximum elevations of the energy gradients that the pump will be operating against at the beginnning of priming, at low tailwaters, and at the maximum expected tailwater. The hydrostatic head or

hydraulic gradient elevation at various locations along the siphon was measured using piezometers. These data were plotted and the profile extrapolated to sta 0+00, which is the location of the prototype pump (Plates 3-5). The hydraulic grade-line elevation determined in the model was reduced to account for differences in the hydraulic resistance and Reynolds number of flow between the model and prototype. The model was assumed to be a smooth pipe with Darcy-Weisbach friction factors between 0.018 and 0.014. Prototype friction factors are expected to range between 0.010 and 0.013 and were calculated from the friction losses estimated by the designers (LMM) for vinyl-coated steel pipe. Results of the procedure used to adjust for frictional differences are shown in Table 1. When the siphon trap was submerged and the tailwater controlled the head in the siphon, an additional adjustment to the head losses was required because the increaser at the outlet (from 7-ft-diam pipe to a 10-ft square box) was not simulated in the 1:9.6-scale model. Calculations to determine this adjustment are shown in Table 2. The calculations for the adjusted head elevations at the pump for various discharges are shown in Tables 3-5. Results are plotted in Plates 6-8.

32. The primary function of this model investigation was to study the siphon's priming characteristics and washout potential, phenomena governed primarily by gravity forces. When the siphon is primed, viscous forces become more important. In order to use the model to estimate head losses in the siphon, it was necessary to make adjustments to the data to account for incorrectly scaled roughness elements. The assumptions required to make the necessary adjustments render the results only as reliable as normal hydraulic calculations used to determine head losses in a closed conduit. Head losses computed by theoretical equations are compared with the adjusted model results in Plate 9.

Pressure Fluctuations at Pump

33. Pressure fluctuations were measured in the 1:9.6-scale model with the type 4 design during and after priming of the siphon.

Pressures were measured by an electronic pressure cell mounted flush with the bottom of the pipe; the cell was located 35 ft (prototype) downstream from the pump. The largest variation in pressures occurred during priming, when large air pockets downstream from the hydraulic jump became large enough to move upstream through the jump. Pressure fluctuations as large as 9 ft of water were recorded. Once the siphon was primed, pressure fluctuations were reduced to 2 to 3 ft of water. Maximum observed pressure fluctuations for several operating conditions are shown in Table 6. Actual recorded pressure fluctuations during two simulated priming operations are shown in Figure 13.

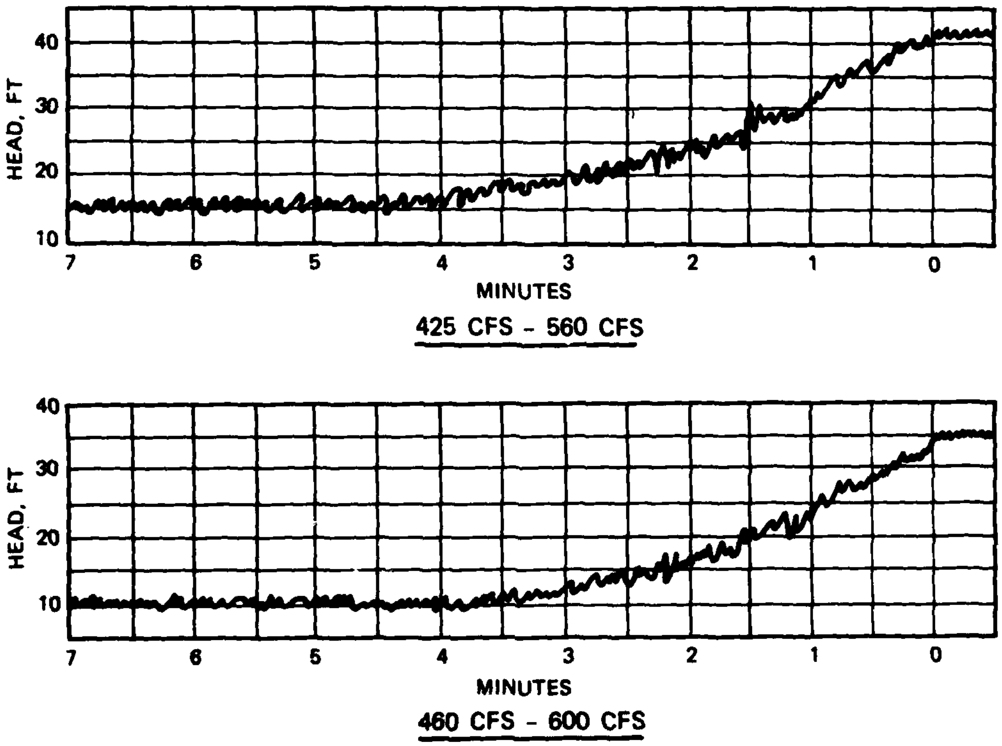

Figure 13. Pressure fluctuations during priming with type 4 design siphon

Surging in Air Vent

34. Surging in the air vent located downstream from the trap crown at el 30.0 was studied in the 1:9.6-scale model of the type 4

(recommended) design siphon. Surging was studied at the beginning of priming with the air vent at the siphon crown open and during normal (primed) operating conditions. A discharge of 600 cfs was used to evaluate surging after the siphon was primed; this is a relatively high discharge based on the expected pump characteristic curves. Pressure fluctuations (measured with piezometers just upstream from the trap crown) were less than 0.5 ft of water for the full range of expected tailwaters. There was no surge in the air vent when the tailwater was below el 28.0; with higher tailwaters, the maximum surge height in the air vent was 3 ft above the tailwater elevation. There was no measurable improvement in maximum surge heights with the addition of a second air vent located downstream at el 27.8. Surge conditions at the beginning of priming were evaluated using a priming discharge of 425 cfs. Pressure fluctuations just upstream from the trap crown were less than 1 ft of water when the tailwater elevation was below 24.0. Pressure fluctuations increased to a maximum of about 3 ft of water with a tailwater at el 32.0 and decreased with higher tailwaters. Maximum surge height in the air vent increased from 0.0 ft of water with tailwater at el 6.0, to 9 ft of water with tailwater at el 20.0, and reached a maximum of 25 ft of water above the tailwater at higher tailwater elevations. With a second air vent added at el 27.8, the surge was eliminated when the tailwater was below el 24.0 but was just as severe with the higher tailwaters. With two air vents, air can be drawn into the siphon downstream from the trap during priming, affording a certain degree of stability to the hydrostatic pressure at the trap crown when the tailwater is below el 24.0. When the second air vent is submerged this advantage is lost. The increased hydrostatic pressure at the trap crown that occurred with a single air vent actually is a boost to priming in this case; therefore, the second vent is not recommended. Measurements of surge height and pressure fluctuations in the air vent at el 30.0 are shown in Tables 7 and 8.

35. Protection of the levee from surge flows out of the air vent were not studied in this investigation. It is recommended, however, that the top of the air vent be extended to el 50.0 to allow for

containment of surges during normal (primed) operating conditions. Provision should be made to protect the levee from surge flow that will spill out of the air vents during priming.

Model Scale Effects

36. Model scale effects were investigated by comparing results from the 1:9.6-scale model of the type 4 design siphon with results from a 1:16.8-scale model of the same siphon. Priming times for a range of discharges (with the tailwater below the outlet) are compared in Table 9. As expected, priming times were significantly longer in the 1:16.8-scale model. There was also a significant difference in the ability to maintain the priming seal. In the 1:16.8-scale model, a discharge of 640 cfs (the maximum discharge that could be simulated in the model) did not wash out the priming seal. In the 1:9.6-scale model, the priming seal washed out at a discharge of 530 cfs. These differences are partly due to the differences in Reynolds number of flow and hydraulic resistance of the two models; but the primary reason for the variation is related to problems of modeling the entrainment, mixing and transport of air and water. The larger, 1:9.6-scale model will more closely simulate the prototype. It is recommended that provision for prototype discharge and pressure measurements be included in the project so that direct comparisons of model and prototype results can be made and more information on scale effects in siphon modeling can be obtained.

Calculating Priming Head

37. Current Corps of Engineers design guidance (OCE 1962) recommends that the priming head at the pump be computed by calculating the pipe losses and the velocity head and then adding these to the elevation of the top of the siphon. Karassik et al. (1976) recommend using one-half the critical depth at the top of the siphon as the elevation to which the pipe losses and velocity head should be added. Another

possible base is the critical depth elevation. Calculations using all three methods were made by the U. S. Army Engineer District, Memphis, and are compared with model results in Figure 14. Model results indicate that the best way to compute priming head at the pump is to add the velocity head and the head losses to the critical depth elevation at the siphon crown.

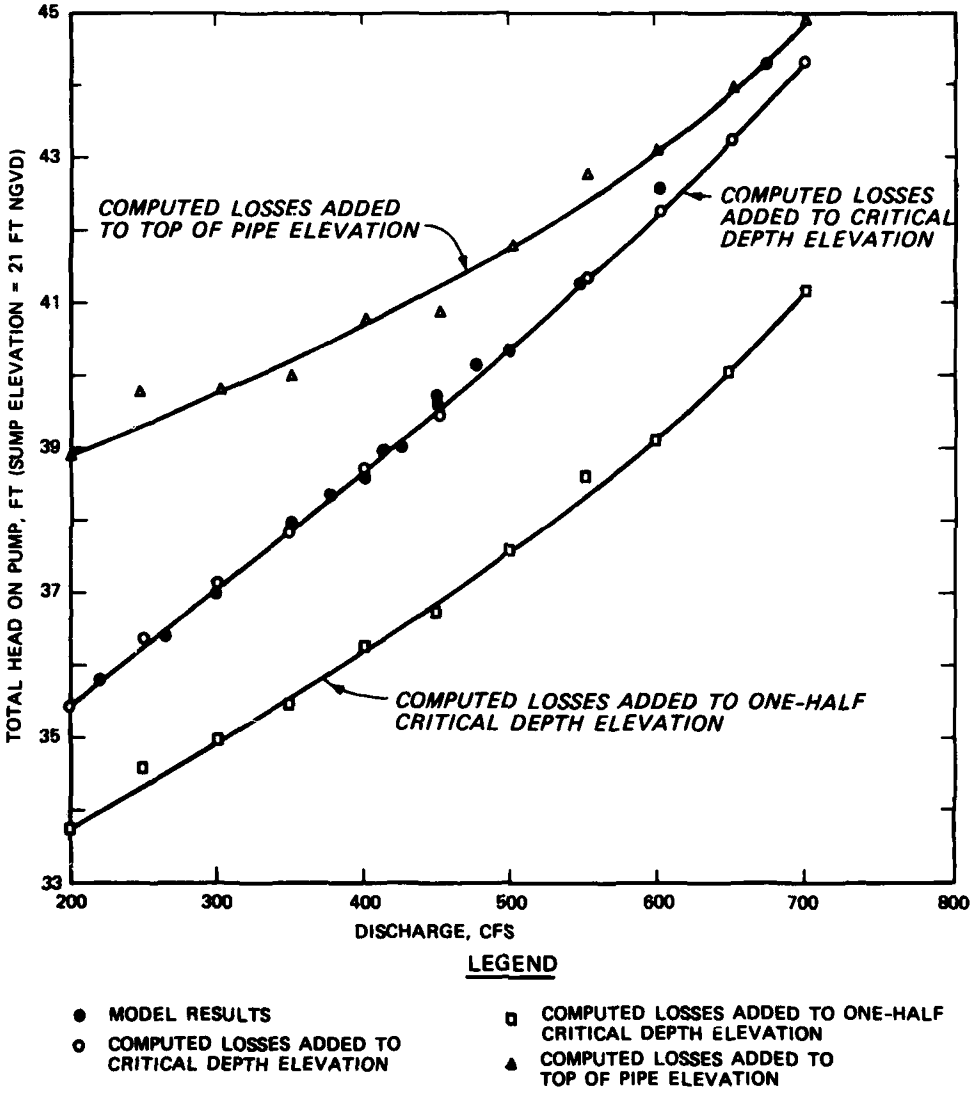

Figure 14. Comparison of methods for computing priming head

PART IV: CONCLUSIONS AND RECOMMENDATIONS

38. Pumping station siphons must be designed so that velocities are sufficient to remove air with the priming discharge and yet maintain a priming seal upstream from any open air vents or an unsubmerged outlet. A priming seal can be maintained for relatively low tailwaters and open channel flows by incorporating a trap in the downstream leg of the siphon. Water flows down the riverward leg of the siphon until it reaches the base of the trap, where it must flow up an adverse slope to the trap crown. When the upward leg of the trap is flowing full, a hydraulic jump occurs upstream that serves to entrain air so that priming will occur. The crest elevation of the vented trap determines the maximum amount of siphonic recovery that can occur when the siphon is primed. The height of the upward leg of the vented trap determines the capacity of the trap to maintain the priming seal. The recommended type 4 design siphon developed during this model investigation established a design which provided an adequate velocity in the siphon for priming and an adequate trap height for the Pointe Coupee pumping station siphon.

39. Priming characteristics may be studied qualitatively using model studies, realizing that there is a definite scale effect in modeling a water and air mixture. The priming times in prototypes will be less than those observed in models. This provides for a built-in safety factor, because if the model primes it is safe to predict that the prototype will prime. Conversely, the discharge that will wash out the priming seal may be underestimated by a model. It is therefore prudent to provide a safety factor in the design of a vented trap's height. Siphon models should be constructed large enough to ensure reasonable air transport and to minimize scale effects.

40. It was concluded that using nappe deflectors to force priming of the siphon was infeasible for the Pointe Coupee pumping station siphon. Deflectors located on the downward leg of the siphon were unable to force priming at expected priming discharges. Further increases in the deflector's size would have resulted in excessive head losses in

the siphon after priming. Deflectors located at the siphon crown would not function adequately because the siphon's diameter was too large for the expected priming discharges.

41. Flow in siphons pulsates due to the upstream movement of air pockets during priming. Pressure fluctuations as high as 9 ft of water were recorded at the pump for the recommended design. These pressure fluctuations were reduced to 2 to 3 ft of water once the siphon was primed. It is recommended that the top of the air vent be extended to el 50.0 to allow for containment of surges during normal (primed) operating conditions. The pulsating flow observed during priming caused surges in the air vent up to 25 ft above the tailwater. Adequate protection of the levee should be provided at the air vent outlets.

42. It is recommended that provision for prototype discharge and pressure measurements be included in the project design. Data collected from the prototype siphon will aid in the design of future pumping station siphons. In addition, direct comparisons of model and prototype data will provide valuable information relating to scale effects related to siphon modeling.

43. Model results indicate that the best way to compute priming head at the pump is to add the velocity head and the head losses to the critical depth elevation at the siphon crown.

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Table 1

Adjustment for Head Losses Due to Model and Prototype Frictional Differences

Type 4 Design Siphon, 1:9.6-Scale Model

Discharge Prototype cfs Q_p	Velocity Model fps V_m	Reynolds Number Model* $\times 10^5$ R_m	Darcy-Weisbach Friction Factor** Model f_m	Darcy-Weisbach Friction Factor† Prototype f_p	Velocity Head Prototype $V_p^2/2g$	Friction Head Adjustment Prototype feet†† L = 678 ft	L = 528 ft	L = 282 ft
220	1.84	1.11	0.0175	0.0128	0.51	0.23	0.18	0.10
265	2.22	1.34	0.0172	0.0126	0.74	0.33	0.26	0.14
300	2.52	1.53	0.0166	0.0121	0.94	0.41	0.31	0.17
350	2.94	1.78	0.0160	0.0116	1.29	0.55	0.43	0.23
375	3.14	1.91	0.0158	0.0115	1.48	0.62	0.48	0.26
400	3.36	2.04	0.0156	0.0114	1.68	0.68	0.53	0.28
425	3.56	2.17	0.0154	0.0112	1.90	0.77	0.60	0.32
450	3.77	2.29	0.0152	0.0111	2.13	0.85	0.66	0.35
475	3.98	2.42	0.0151	0.0110	2.37	0.94	0.73	0.39
500	4.19	2.55	0.0149	0.0110	2.62	0.99	0.77	0.41
525	4.40	2.68	0.0147	0.0108	2.89	1.09	0.85	0.45
550	4.61	2.80	0.0146	0.0107	3.18	1.20	0.94	0.50
600	5.03	3.06	0.0144	0.0106	3.78	1.39	1.08	0.58
640	5.37	3.26	0.0142	0.0104	4.30	1.58	1.23	0.66
680	5.70	3.46	0.0140	0.0103	4.85	1.74	1.35	0.72

* Temperature = 60°F.

** Model assumed to be smooth pipe.

† f_p calculated from friction head losses computed by Memphis District for vinyl-coated steel pipe.

†† Head adjustment = $(f_m - f_p) \frac{L}{D} \frac{Vp^2}{2g}$

L = Length of pipe flowing full.
= 282 ft when air vent at crown open.
= 528 ft at low tailwaters when critical depth occurs at trap crown.
= 678 ft at high tailwaters when entire siphon is flowing full.

Table 2
Adjustment for Head Losses due to Increaser

Type 4 Design Siphon, 1:9.6-Scale Model

1 Discharge Prototype cfs Q_p	2 Exit Loss* Without Increaser ft $k_o V_p^2/2g$	3 Head** Loss due to Increaser ft $k_i V_p^2/2g$	4 Velocity at Exit with Increaser V_{2p}, fps	5 Exit Loss* with Increaser ft $k_o V_{2p}^2/2g$	6 Total Loss with Increaser ft Col 3 + Col 5	7 Head Adjustment due to Increaser Col 2 - Col 6
350	1.29	0.06	3.50	0.19	0.25	1.04
375	1.48	0.07	3.75	0.22	0.29	1.19
400	1.68	0.08	4.00	0.25	0.33	1.35
425	1.90	0.10	4.25	0.28	0.38	1.52
450	2.13	0.11	4.50	0.31	0.42	1.71
475	2.37	0.12	4.75	0.35	0.47	1.90
500	2.62	0.13	5.00	0.39	0.52	2.10
525	2.89	0.14	5.25	0.43	0.57	2.32
550	3.18	0.16	5.50	0.47	0.63	2.55
600	3.78	0.19	6.00	0.56	0.75	3.03
640	4.30	0.27	6.40	0.64	0.86	3.45
680	4.85	0.24	6.80	0.72	0.96	3.89

Note: V_p = prototype velocity in siphon (7-ft diam).
V_{2p} = prototype velocity at exit (10-ft square box).
* k_o = 1.0.
** k_i = 0.05.

Table 3

Head Elevations at Pump at Start of Priming

Type 4 Design Siphon, 1:9.6-Scale Model

Discharge cfs	Hydraulic Grade Line at Pump* el	Head Ajustment for Friction** ft	Adjusted Hydraulic Grade Line el	Velocity Head ft	Adjusted Total Head el
220	56.4	0.1	56.3	0.5	56.8
265	56.8	0.1	56.7	0.7	57.4
300	57.3	0.2	57.1	0.9	58.0
350	57.9	0.2	57.7	1.3	59.0
410	58.5	0.3	58.2	1.8	60.0
450	58.8	0.4	58.4	2.1	60.5
500	59.2	0.4	58.8	2.6	61.4
540	59.7	0.5	59.2	3.1	62.3
600	60.4	0.6	59.8	3.8	63.6
675	61.2	0.7	60.5	4.8	65.3

Note: All elevations are in feet referred to NGVD.
* Extrapolated from model data in Plate 3.
** Table 1 (L = 282 ft).

Table 4

Head Elevations at Pump, Tailwater Below El 20.0

Type 4 Design Siphon, 1:9.6-Scale Model

Discharge cfs	Hydraulic Grade Line at Pump* el	Head Ajustment for Friction** ft	Adjusted Hydraulic Grade Line at Pump el	Velocity Head $V^2/2g$ ft	Adjusted Total Head at Pump el
350	31.6	0.4	31.2	1.3	32.5
375	31.9	0.5	31.4	1.5	32.9
400	32.4	0.5	31.9	1.7	33.6
425	32.7	0.6	32.1	1.9	34.0
450	33.1	0.7	32.4	2.1	34.5
475	33.6	0.7	32.9	2.4	35.3
500	34.1	0.8	33.3	2.6	35.9
525	34.8	0.8	34.0	2.9	36.9
550	35.3	0.9	34.4	3.2	37.6
600	36.7	1.1	35.6	3.8	39.4
640	38.0	1.2	36.8	4.3	41.1
680	39.3	1.4	37.9	4.8	42.7

Note: All elevations are in feet referred to NGVD.
* Extrapolated from model data in Plate 4.
** Table 1 (L = 528 ft).

Table 5

Head Elevations at Pump

Tailwater El 46.0

Type 4 Design Siphon, 1:9.6-Scale Model

Discharge cfs	Hydraulic Grade Line at Pump* el	Head Adjustment for Friction** ft	Head Adjustment for Increaser† ft	Adjusted Hydraulic Grade Line el	Velocity Head ft	Adjusted Total Head el
350	48.9	0.6	1.0	47.3	1.3	48.6
375	49.5	0.6	1.2	47.7	1.5	49.2
400	49.9	0.7	1.4	47.8	1.7	49.5
425	50.6	0.8	1.5	48.3	1.9	50.2
450	51.0	0.8	1.7	48.5	2.1	50.6
475	51.6	0.9	1.9	48.8	2.4	51.2
500	52.4	1.0	2.1	49.3	2.6	51.9
525	53.3	1.1	2.3	49.9	2.9	52.8
550	54.0	1.2	2.6	50.2	3.2	53.4
600	55.6	1.4	3.0	51.2	3.8	55.0
640	57.1	1.6	3.4	52.1	4.3	56.4
680	58.5	1.7	3.9	52.9	4.8	57.7

Note: All elevations are in feet referred to NGVD.
* Extrapolated from model data in Plate 5.
** Table 1 (L = 678 ft).
† Table 2.

Table 6

Pressure Fluctuations at Pump

Type 4 Design Siphon, 1:9.6-Scale Model

Discharge cfs	Tailwater Elevation ft	Siphon Operation	Maximum Pressure Fluctuation Feet of Water
425	10	Priming	8
425	28	Priming	9
425	46	Priming	5
460	10	Priming	9
425-560	10	Priming	7
460-600	10	Priming	7
600	10	Primed	2
600	28	Primed	3
600	46	Primed	2

Note: All elevations are in feet referred to NGVD.

Table 7

Surge in Air Vent at El 30.0

Normal (Primed) Operating Conditions

Discharge 600 cfs

Type 4 Design Siphon, 1:9.6-Scale Model

	With One Vent			With Two Vents		
Tailwater Elevation ft	Pressure Fluctuations Upstream from Trap ft	Maximum Surge Elevation ft	Maximum Surge Height Above Tailwater* ft	Pressure Fluctuations Upstream from Trap ft	Maximum Surge Elevation ft	Maximum Surge Height Above Tailwater* ft
8	0.1	--	--	0.1	--	--
10	0.2	--	--	0.1	--	--
12	0.2	--	--	0.1	--	--
14	0.2	--	--	0.1	--	--
16	0.2	--	--	0.1	--	--
18	0.2	--	--	0.1	--	--
20	0.2	--	--	0.1	--	--
25	0.2	--	--	0.1	--	--
27	0.2	--	--	0.2	--	--
29	0.4	34	--	0.4	33	--
31	0.3	34	3	0.5	34	3
35	0.4	38	3	0.4	38	3
40	0.3	43	3	0.4	43	3
46	0.4	48	2	0.4	49	3

Note: All elevations are in feet referred to NGVD.
* Calculated only when air vent submerged.

Table 8

Surge in Air Vent at El 30.0 at Start of Priming

Discharge 425 cfs

Type 4 Design Siphon, 1:9.6-Scale Model

	With One Vent			With Two Vents		
Tailwater Elevation ft	Pressure Fluctuations Upstream from Trap ft	Maximum Surge Elevation ft	Maximum Surge Height Above Tailwater* ft	Pressure Fluctuations Upstream from Trap ft	Maximum Surge Elevation ft	Maximum Surge Height Above Tailwater* ft
4	0.2	--	--	0.2	--	--
6	0.2	--	--	0.2	--	--
8	0.3	32	--	0.2	--	--
10	0.6	34	--	0.3	--	--
12	0.6	34	--	0.2	--	--
14	0.4	33	--	0.2	--	--
16	0.5	35	--	0.2	--	--
18	0.4	37	--	0.2	--	--
20	0.5	39	--	0.2	--	--
22	0.7	41	--	0.2	--	--
24	1.0	44	--	0.2	--	--
26	1.0	47	--	0.6	34	--
28	2.7	50	--	1.3	42	--
30	2.7	52	22	1.3	48	18
32	3.0	57	25	2.0	54	22
34	2.7	57	23	2.7	57	23
36	2.5	>60	>24	2.0	59	23
38	--	--	--	1.8	56	18
40	--	--	--	1.5	57	17

Note: All elevations are in feet referred to NGVD.
* Calculated only when air vent submerged.

Table 9

Scale Effects on Priming Characteristics

Type 4 Design Siphon

Tailwater Below Outlet

Discharge cfs	Priming Time (Prototype) 1:9.6-Scale Model min	1:16.8-Scale Model min
350	330	--
375	117	420
400	48	326
425	23	96
450	13	46
475	8	30
500	6	10
525	4	5
550	Washout	6
600	Washout	6
640	Washout	2

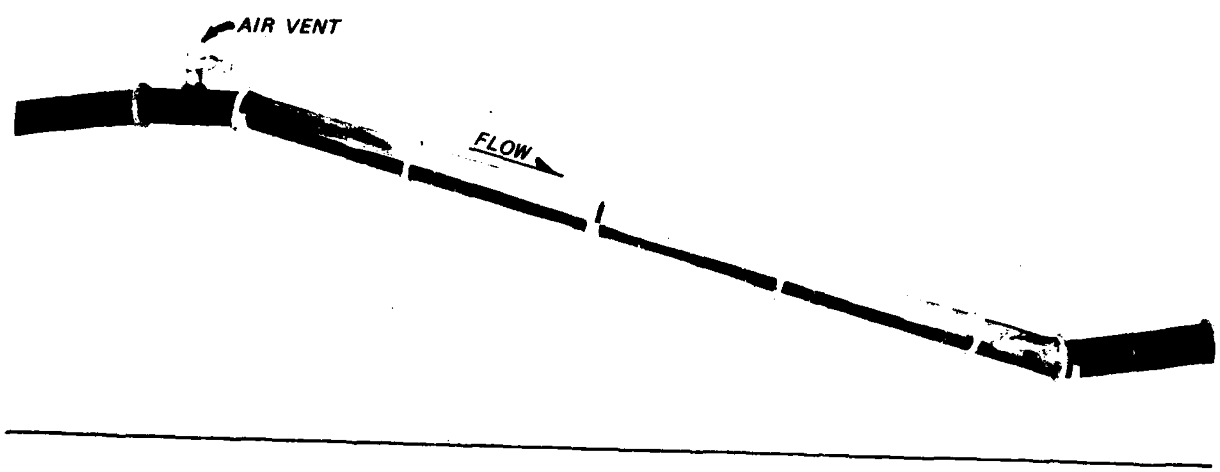


Photo 1. 1:9.6-scale model of type 3 design siphon, priming characteristics; discharge 425 cfs, t = 0 sec

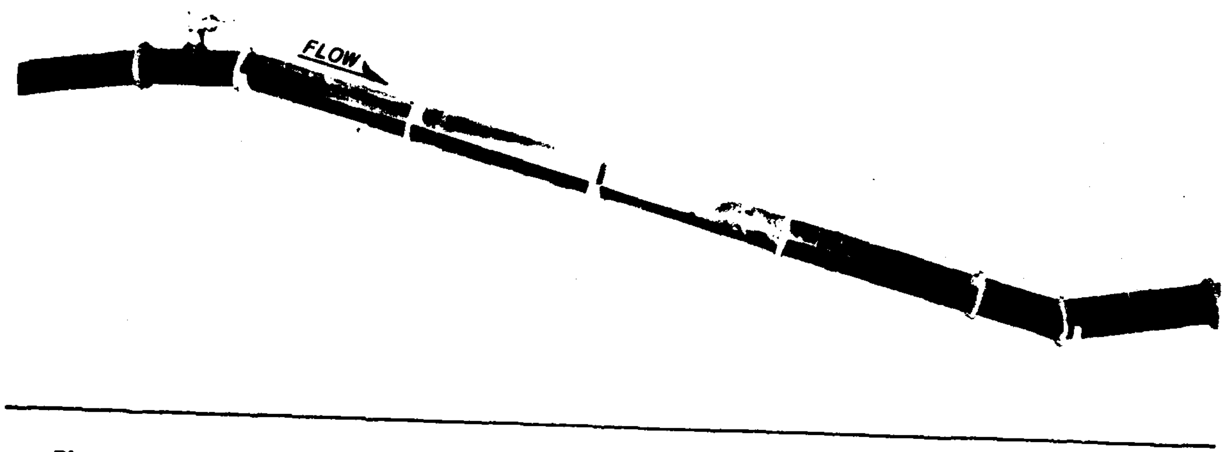


Photo 2. 1:9.6-scale model of type 3 design siphon, priming characteristics; discharge 425 cfs, t = 45 sec

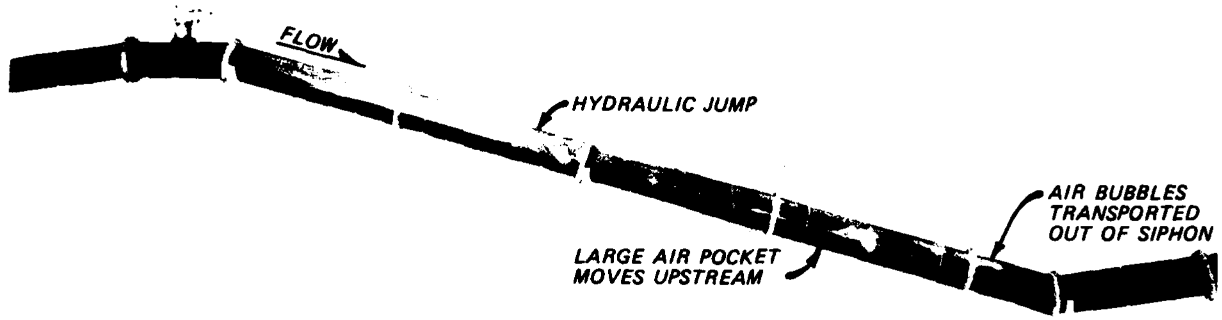


Photo 3. 1:9.6-scale model of type 3 design siphon, priming characteristics; discharge 425 cfs, t = 1.6 min

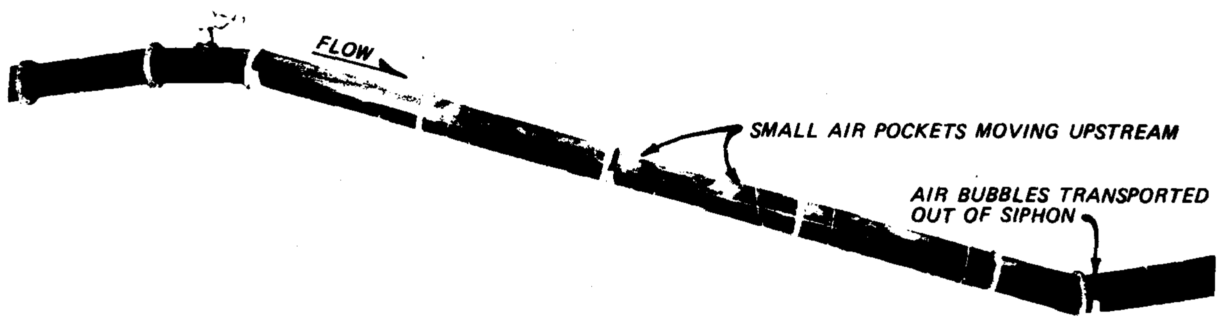


Photo 4. 1:9.6-scale model of type 3 design siphon, priming characteristics; discharge 425 cfs, t = 3.1 min

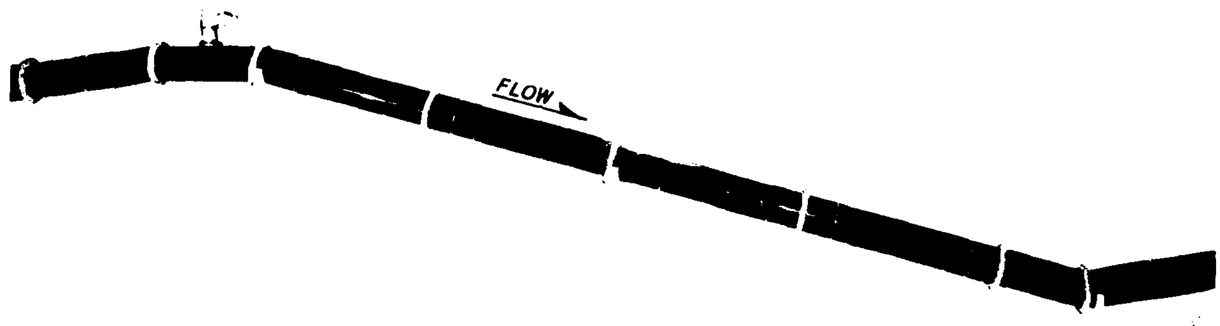
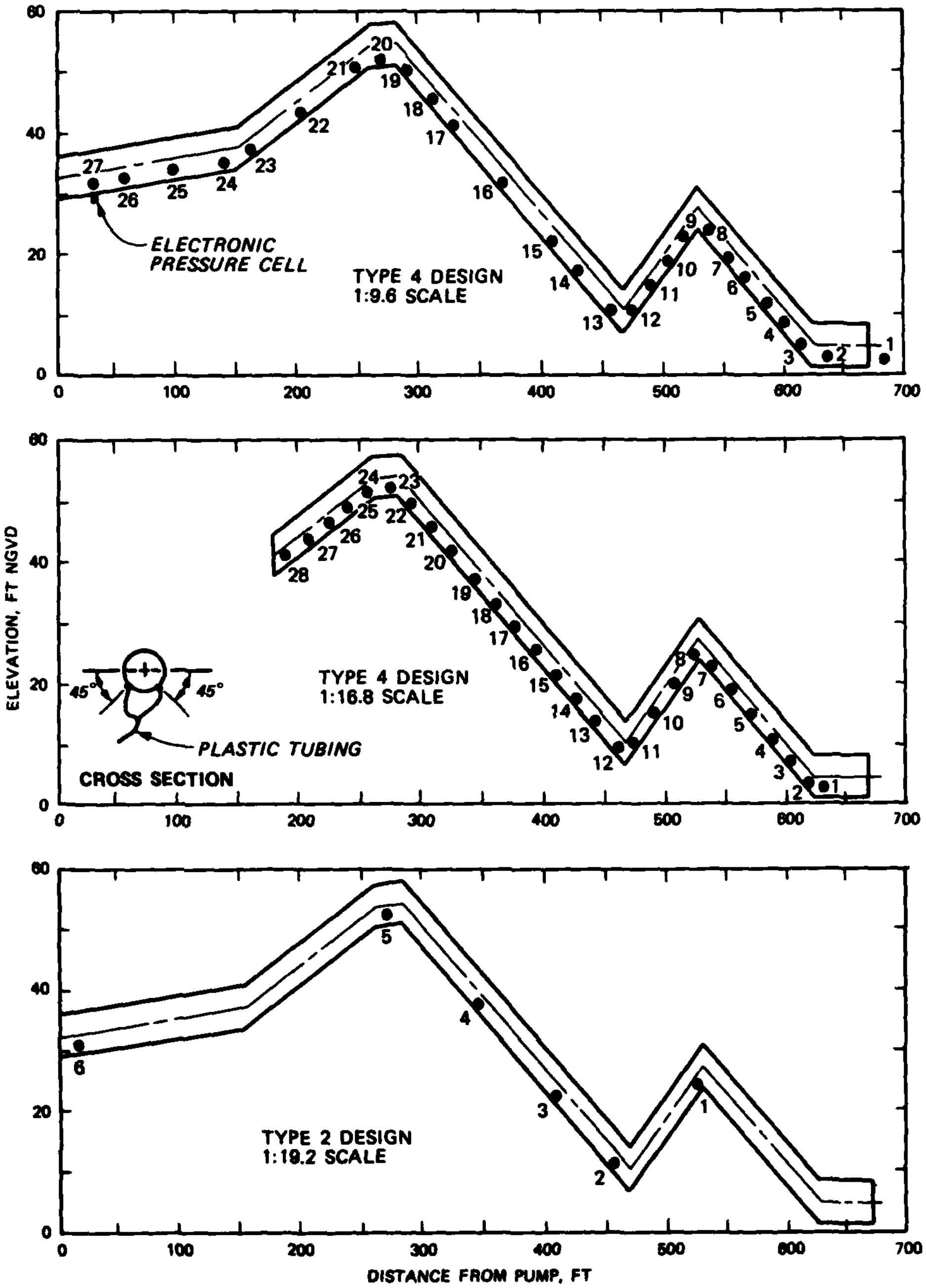


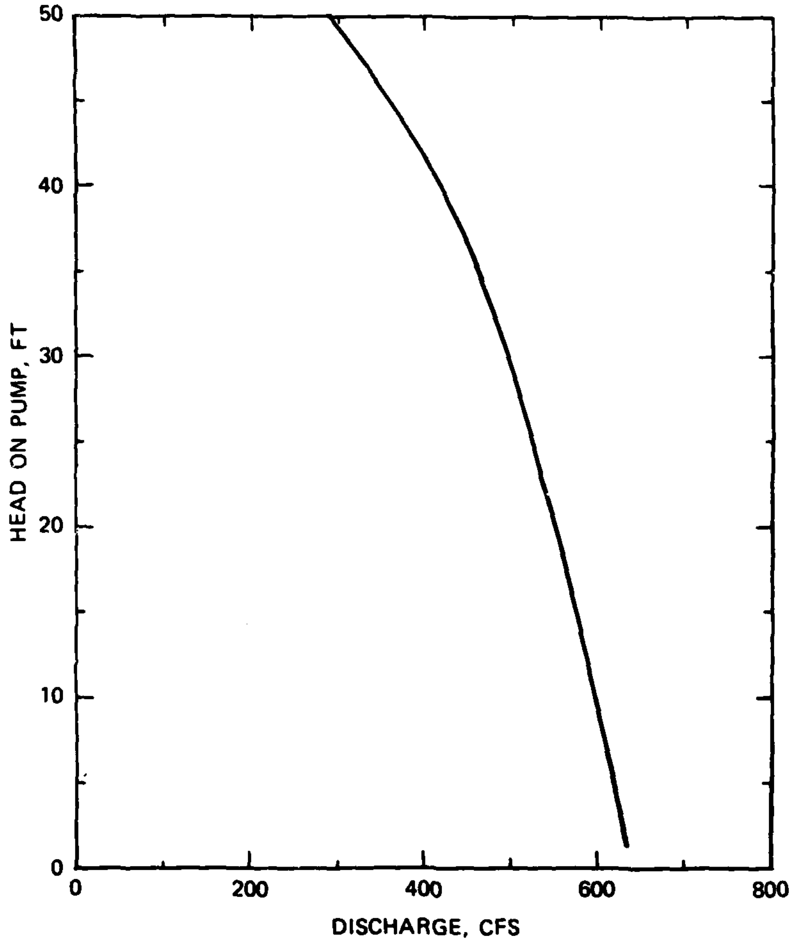
Photo 5. 1:9.6-scale model of type 3 design siphon, priming characteristics; discharge 425 cfs, t = 18.6 min (primed)

Photo 6. 1:9.6-scale model of type 3 design siphon, washout of priming seal, discharge 450 cfs. Hydraulic jump moves from bottom of pipe, up adverse slope, and disappears over the crown



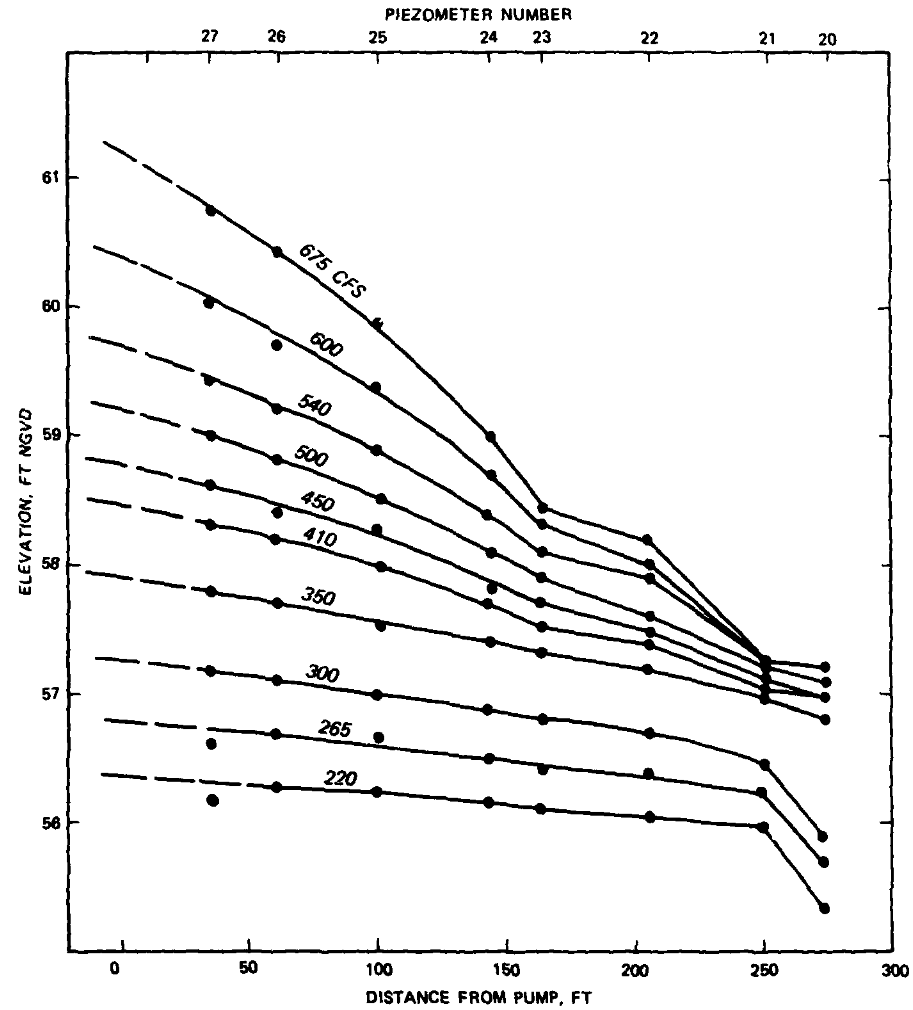
PIEZOMETER LOCATIONS

PLATE 1



POSSIBLE PUMP
CHARACTERISTIC CURVE

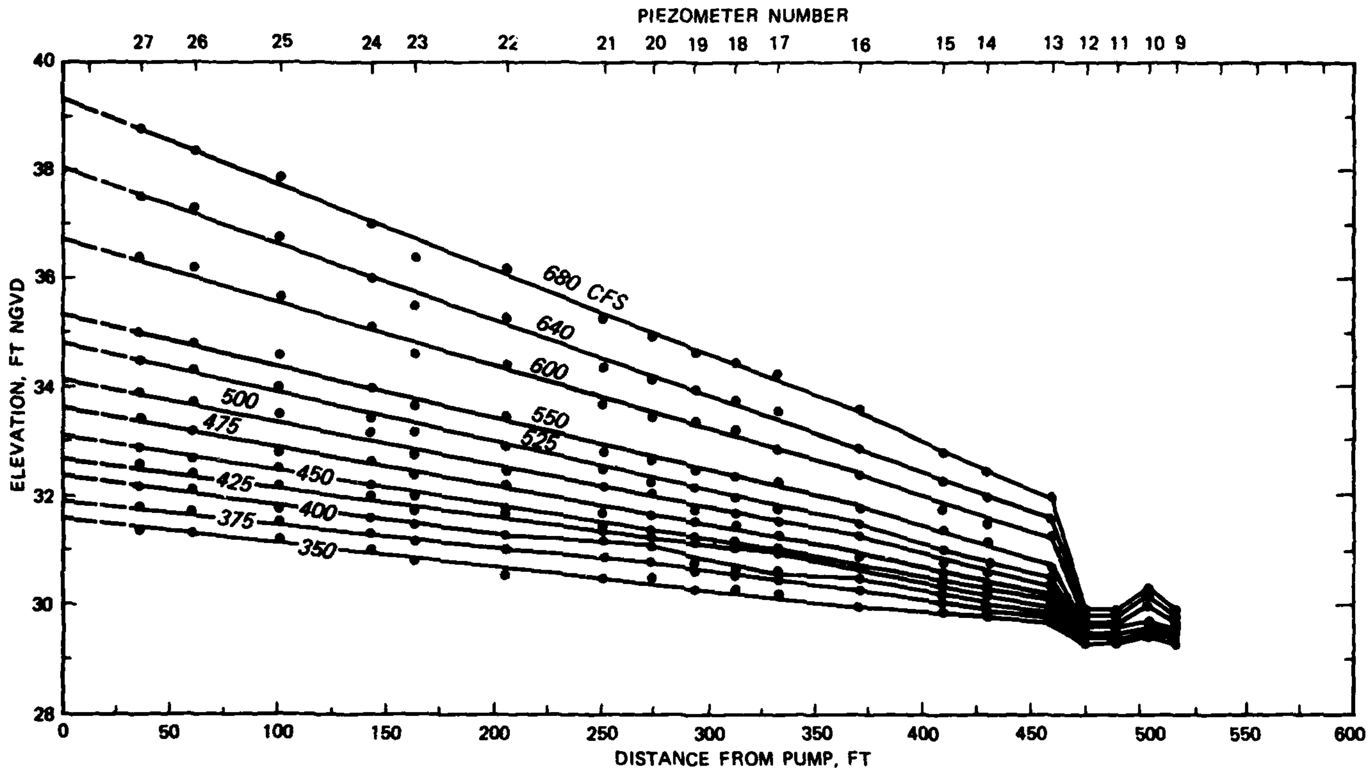
PLATE 2



HYDRAULIC GRADE LINE
START OF PRIMING

AIR VENT OPEN

TYPE 4 (RECOMMENDED) DESIGN

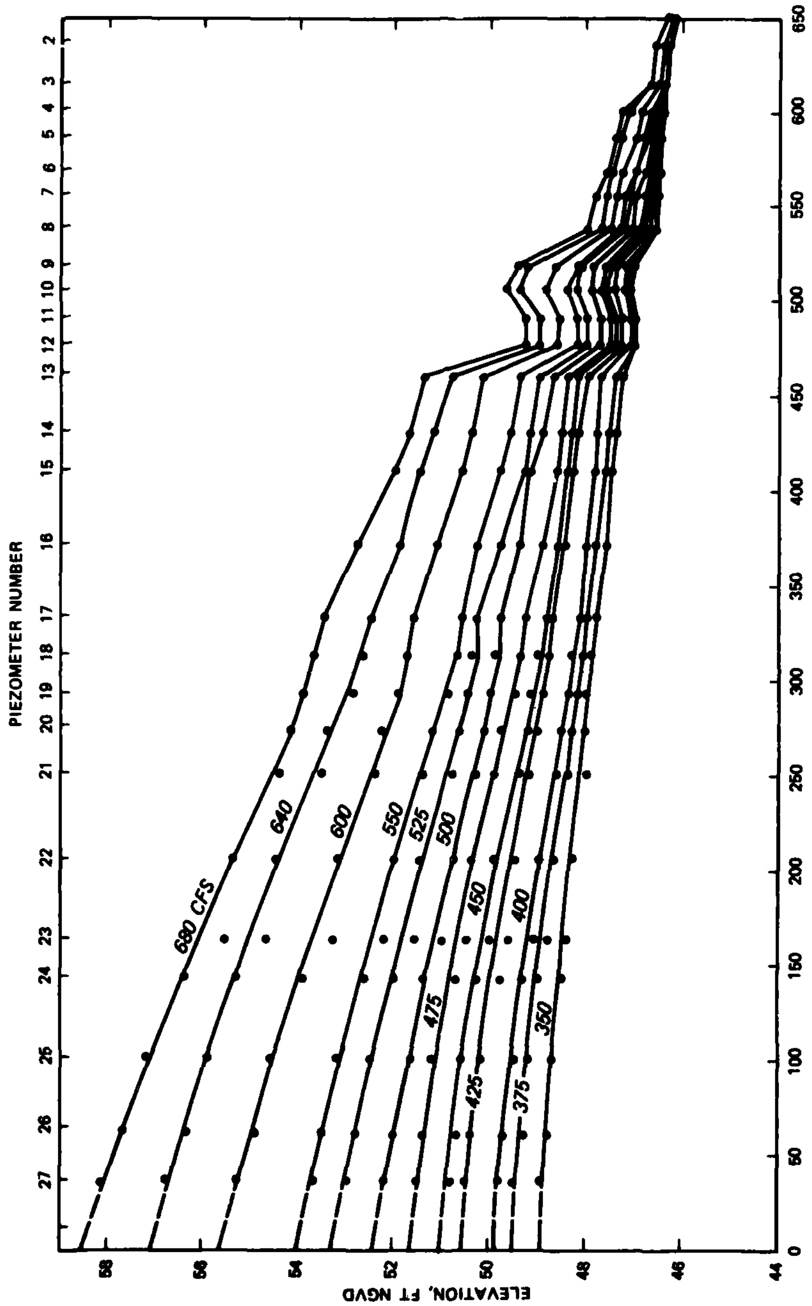


HYDRAULIC GRADE LINE

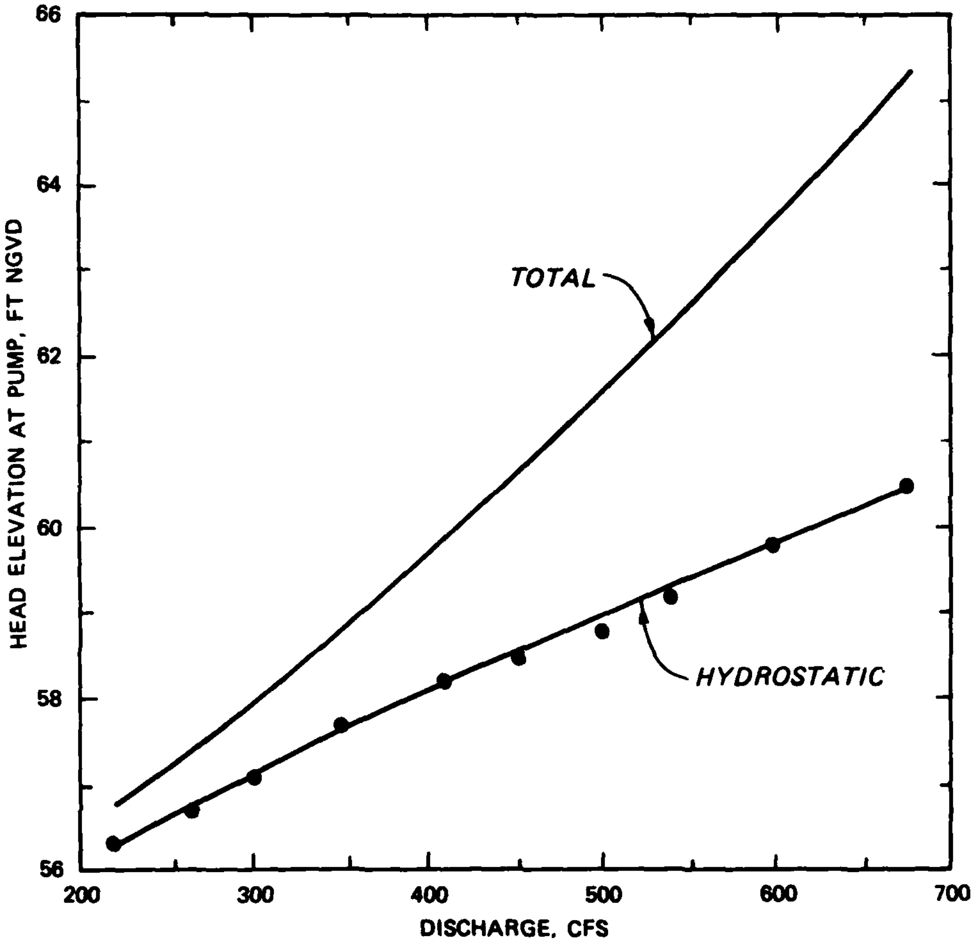
TAILWATER BELOW EL 20

SIPHON PRIMED

TYPE 4 (RECOMMENDED) DESIGN

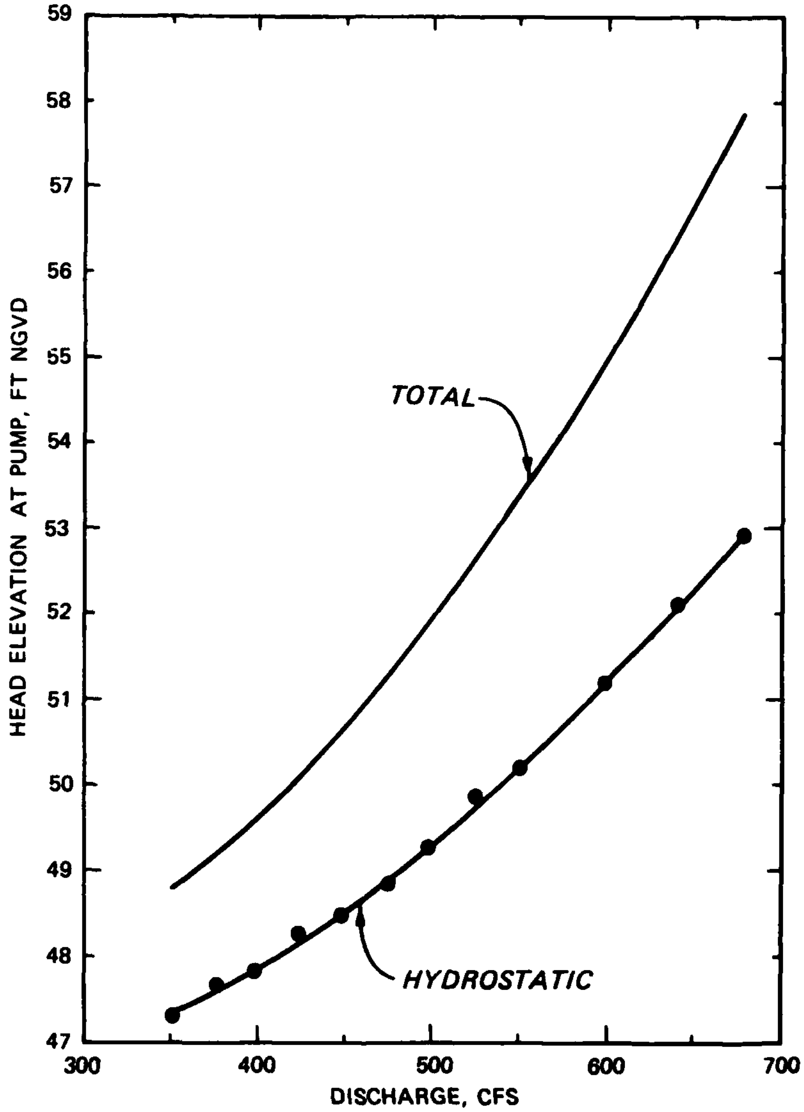


HYDRAULIC GRADE LINE
TAILWATER EL 46
SIPHON PRIMED
TYPE 4 (RECOMMENDED) DESIGN



HEAD ELEVATIONS AT PUMP
START OF PRIMING
AIR VENT OPEN

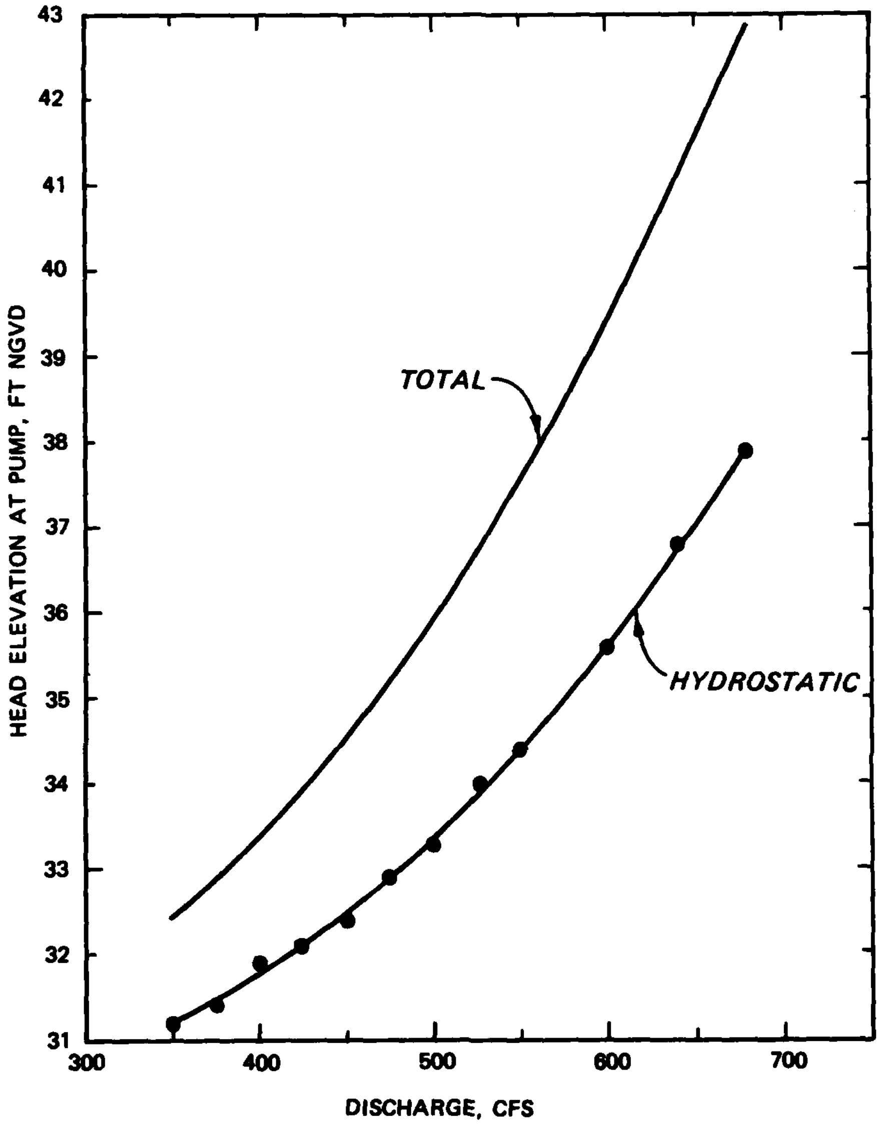
TYPE 4 (RECOMMENDED) DESIGN



HEAD ELEVATIONS AT PUMP SIPHON PRIMED

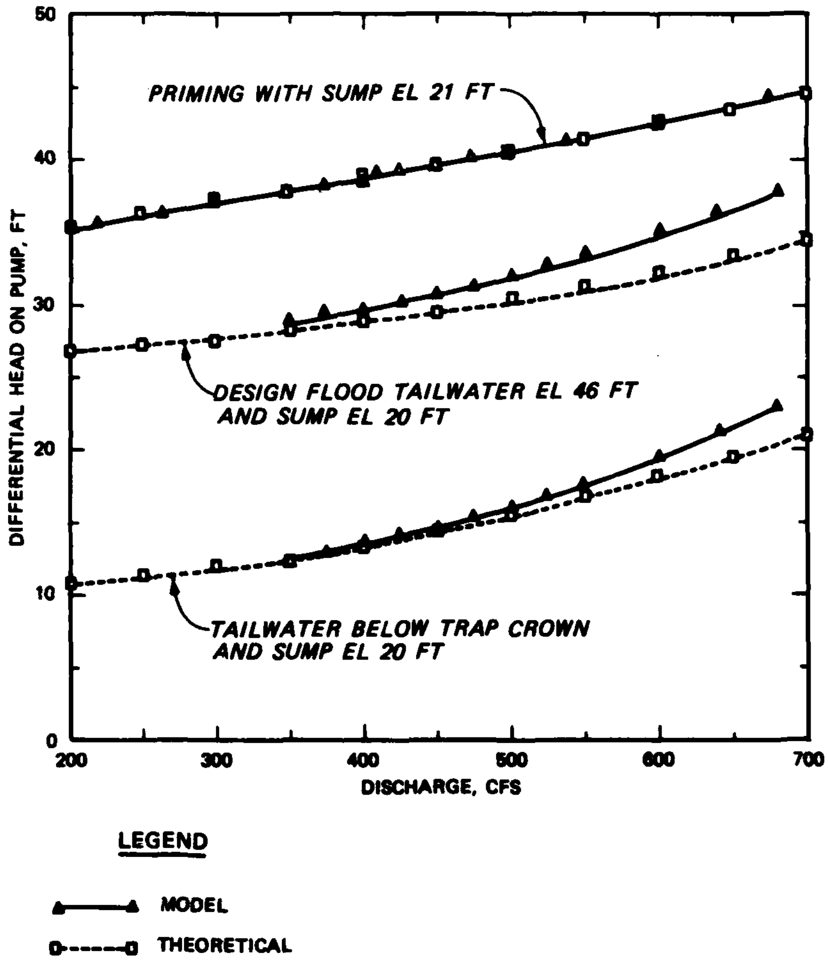
TAILWATER EL 46

TYPE 4 (RECOMMENDED) DESIGN



HEAD ELEVATIONS AT PUMP
SIPHON PRIMED
TAILWATER BELOW TRAP CROWN

TYPE 4 (RECOMMENDED) DESIGN



HEAD ON PUMP

COMPARISON OF THEORETICAL AND MODEL DATA

TYPE 4 (RECOMMENDED) DESIGN

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Copeland, Ronald R.
Pointe Coupee pumping station siphon, Upper Pointe Coupee Loop Area, Louisiana : Hydraulic Model Investigation / by Ronald R. Copeland (Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. ; available from NTIS, 1982.
35, [13] p., 9 p. of plates : ill. ; 27 cm. -- (Technical report ; HL-82-21)
Cover title.
"September 1982."
Final report.
"Prepared for U.S. Army Engineer District, New Orleans."
Bibliography: p. 34-55.

1. Hydraulic models. 2. Point Coupee Pumping Station (La.) 3. Pumping stations. 4. Siphons. I. United States. Army. Corps of Engineers. New Orleans District. II. U.S.

Copeland, Ronald R.
Pointe Coupee pumping station siphon, Upper : ... 1982.
(Card 2)

Army Engineer Waterways Experiment Station. Hydraulics Laboratory. III. Title IV. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; HL-82-21.
TA7.W34 no.HL-82-21

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